SPAWAR
Systems Center
San Diego

TECHNICAL DOCUMENT 3052
December 1998

Copper Loading to U.S. Navy Harbors

Norfolk, VA; Pearl Harbor, HI; and San Diego, CA

H. D. Johnson
J. G. Grovhoug
SSC San Diego

A. O. Valkirs
Computer Sciences Corporation

SSC San Diego

TECHNICAL DOCUMENT 3052
December 1998

Copper Loading to U.S. Navy Harbors

Norfolk, VA; Pearl Harbor, HI; and San Diego, CA

H. D. Johnson
J. G. Grovhoug
SSC San Diego

A. O. Valkirs
Computer Sciences Corporation

Approved for public release; distribution is unlimited.

SPAWAR Systems Center San Diego

SSC San Diego
San Diego, CA 92152–5001

SSC San Diego
San Diego, California 92152–5001

H. A. Williams, CAPT, USN
Commanding Officer

R. C. Kolb
Executive Director

ADMINISTRATIVE INFORMATION

The work described in this document was performed for the Naval Sea Systems Command, Code 005C, by the Marine Environmental Quality Branch, Code D362, SSC San Diego.

Released by
J. G. Grovhoug, Head
Marine Environmental Quality
Branch

Under authority of
R. H. Moore, Head
Environmental Sciences
Division

SB

EXECUTIVE SUMMARY

This document identifies several sources of copper loading into four Navy harbors within the continental United States and Hawaii. The degree of copper loading as dissolved copper is quantified by source within each harbor. Although sources and their respective copper loadings vary between harbors, some similarities are apparent (figure ES-1). In Norfolk, Pearl Harbor, and Little Creek, Navy hull coating leachate is the principal dissolved copper source, ranging from 41 to 61% of the total dissolved copper load. In San Diego Bay, Navy hull coating leachate is the second largest (22% of total loading) dissolved copper loading source behind civilian hull coating leachate (33%).

The category described as "Navy Other Ship Discharges," primarily seawater cooling and firemain discharges, is also an important loading source, ranging from 10 to 24% of total dissolved copper loading in the four harbors studied. Although not a significant loading source in Norfolk and Pearl Harbors, civilian hull leachate loading was calculated as a very important dissolved copper loading source in San Diego Bay and Little Creek, ranging from 25 to 33% of the total dissolved copper loading. Similarly, civilian ship transit and civilian hull cleaning were determined to be important copper loading sources, although not in all harbors and, generally, not at percentages of total loading as high as the sources mentioned above. Other sources were calculated to be smaller loading factors, sometimes contributing less than 1% of the total dissolved copper load. Navy hull cleaning is in this category for all four naval harbors under evaluation.

Harbors also varied in their total dissolved copper loading in terms of kilograms per year. The highest dissolved copper loading was calculated in San Diego Bay at 32,474 kg/yr, followed by Norfolk Harbor at 26,284 kg/yr, Pearl Harbor at 7,781 kg/yr, and Little Creek at 4,962 kg/yr. The degree of loading was largely dependent on the major loading sources identified above.

The dissolved copper loading calculated in this report was based on numerous assumptions, which, in turn, were supported by data that also varied in quality and availability. Consequently, some loading estimates are considered potentially more accurate than others. Navy hull leachate and civilian hull leachate were determined to be the two most significant loading sources in all four Navy harbors. Both were calculated from an average leach rate determined from several years of data collected in San Diego Bay. A simulated leaching apparatus (rotating drum), as well as actual *in situ* leach rate measurements on active naval vessel hulls, were used to make this estimate. The naval leach rate data were used for civilian hull leach rate calculations because civilian data were not available. Consequently, this assumption should be supported by actual *in situ* civilian leach rate data since civilian antifouling paints are not likely to be of the same formulation type as naval paints in service. The naval *in situ* leach rate data should also be improved with more *in situ* measurements on hulls with new coatings.

Clearly, any assumptions may be tested and improved with additional data. Because of the magnitude of the hull leach rate contribution to total dissolved copper loading relative to other sources, and the calculation of this contribution based on a shared leach rate factor, it is felt that additional *in situ* data from both civilian and naval antifouling coatings is warranted. Additional data supporting other assumptions associated with lesser dissolved copper sources would be useful, but it is not anticipated that additional data would dramatically change copper loading from the minor sources identified.

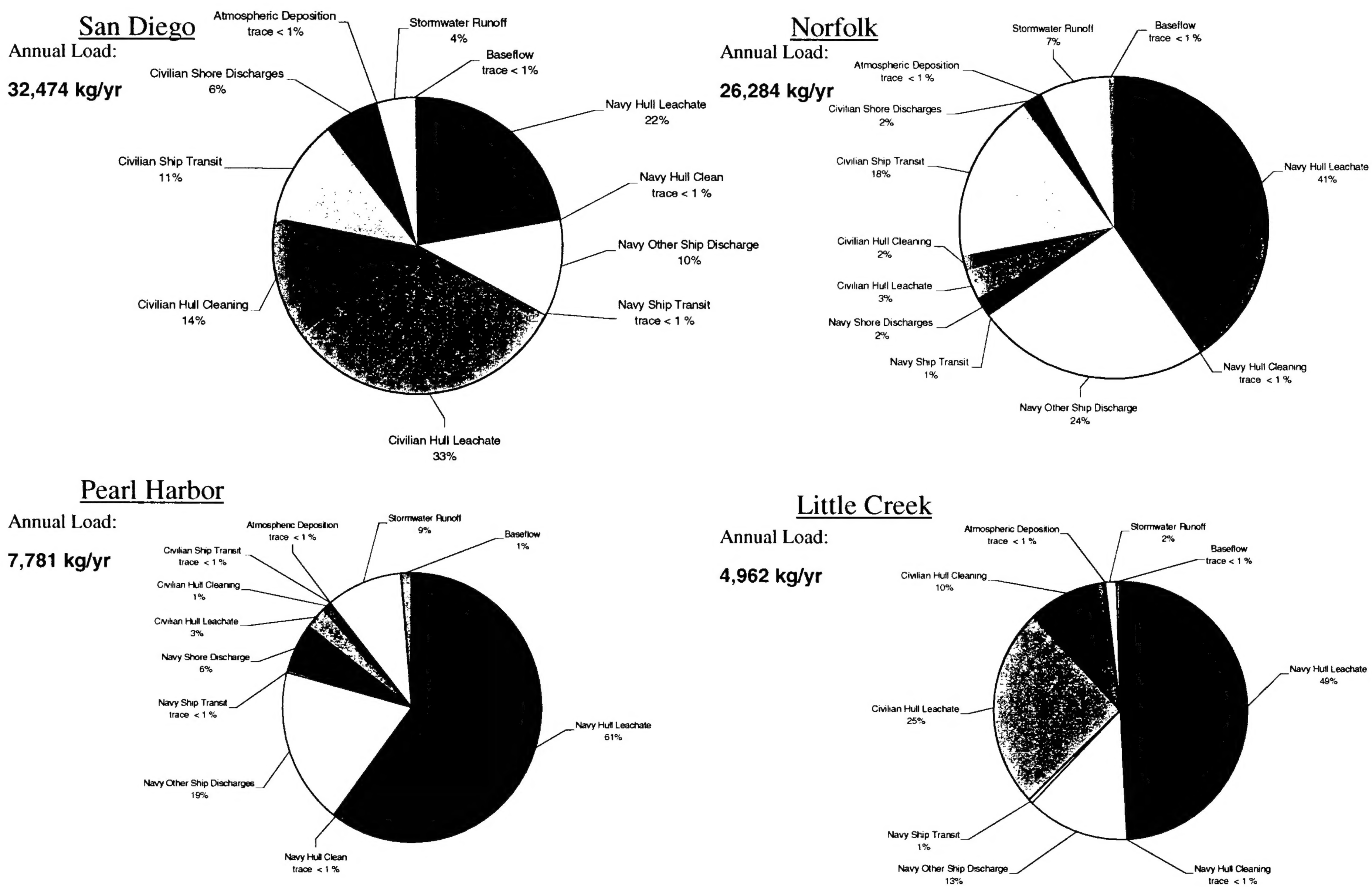


Figure ES-1. Estimated dissolved copper load for four U.S. Navy homeport harbors.

CONTENTS

Figures

Tables

INTRODUCTION

Anthropogenic heavy metals can be a significant threat to the health of marine organisms and, as a result, have come under increased scrutiny by State and Federal regulators in deriving restrictive water quality criteria (WQC). Copper in its dissolved form is one such metal that, although essential to biological functions in trace amounts, can be toxic at higher concentrations.

Copper is a ubiquitous industrial and non-industrial chemical, often exhibiting complex sediment, water, and biotic chemical interactions. This complicates assessment of *in-situ* copper toxicity and represents a significant compliance issue for harbor facilities because stringent water quality criteria have been promulgated during the past decade (Space and Naval Warfare Systems Center, 1998).

The Marine Environmental Quality Branch (Code D362), SSC San Diego, under the sponsorship of Naval Sea Systems Command (00C5), is performing a series of copper mass loading estimates for major harbor areas of the United States that contain significant Navy presence (Bremerton, WA; Mayport, FL; Norfolk, VA; Pearl Harbor, HI; and San Diego, CA). The overall goal of the project is to:

- provide a list of known or potential copper sources within each harbor
- calculate estimates of dissolved copper loading by source
- identify areas where data are non-existent or need improvement

Loading is an important component in determining overall copper mass balance; however, other factors need to be considered to assess the impact a given load will have on receiving water concentration and compliance with water quality criteria. These factors can include system flushing from tidal or wind-driven currents, within harbor transport, sediment deposition, sediment release or binding, mechanical sediment re-suspension, and formation of chemical complexes. Many of these processes are not understood at present and are subject to differing interpretations.

Receiving water-monitoring data with its emphasis on measurements over time provides the best means for gauging long-term effects of copper loading to a system and the relative efficiency of these "removal" factors. Dissolved copper is an active chemical element and is thought to complex in marine waters at a relatively rapid rate (Space and Naval Warfare Systems Center, 1998). The in-water residence time for the biologically toxic portion of dissolved copper may well be on the order of hours (Katz, 1998).

The following sections present the current SSC San Diego copper loading estimates for Norfolk, Pearl Harbor, and San Diego Bay. A brief discussion of the overall copper load estimate is presented for each harbor followed by site-specific loading assumptions pertinent to that location. Appendix A contains the general assumptions, definitions, equations, and data sources for each discharge category. The environmental effects of copper loading are not presented in this study. Space and Naval Warfare Systems Center Technical Document 3034 (1998) contains an excellent recent review of copper chemistry in the marine environment and potential regulatory impacts on Navy and civilian agencies.

NORFOLK AND LITTLE CREEK, VA

Copper contamination is a significant issue in a majority of Chesapeake Bay watersheds (Chesapeake Bay Program, 1991, 1994). The Chesapeake Bay Program has listed copper as the second most important pollutant of concern out of a list of 14 contaminants (Chesapeake Bay Program, 1991).

Naval Station Norfolk, Naval Amphibious Base Little Creek, and assorted Navy shore facilities that comprise Naval Base Norfolk are located on a series of tidally influenced rivers, creeks, and streams along the southern portion of the Chesapeake Bay (figure 1). The majority of these naval activities are adjacent to the Elizabeth River, a 560-km^2 watershed draining into Hampton Roads. Only Naval Amphibious Base Little Creek is within a distinctly different sub-watershed of approximately 19 km^2 that empties directly into Chesapeake Bay. The differences in these two sub-watersheds warrant their consideration as separate entities for this study.

While the U.S. Navy has had a strong presence in the area that dates back over 100 years, Norfolk is also a major commercial seaport and supports a diverse mix of heavy industry along the Elizabeth River. Large tracts of land remain forested or agricultural, reflecting the agricultural history of the region. Increasing residential development, however, is slowly encroaching on these formerly undeveloped areas to support a growing population and economy. The various branches of the Elizabeth River have been heavily industrialized, impacting water and sediment quality (URS Consultants, Inc., 1996). Dredging, bulkheading, fill, and pier construction have modified the river's natural flow. Tidal activity and freshwater flushing is relatively low compared to other regional rivers because of canal locks in the upper river reaches (URS Consultants, Inc., 1996). These canal locks restrict the flow of freshwater to the river, and assist pleasure craft usage on the Elizabeth River, a major artery of the Intercoastal Waterway.

The much larger James River also empties into Hampton Roads from the west. With headwaters in the Virginia mountains over 483 kilometers (300 mi) away, the James River drains a large portion of southern Virginia. River velocity at the outlet near Hampton Roads is estimated to be 226 m^3/s (ft^3/s) (Chesapeake Bay Program, 1994). However, the presence of the Craney Island disposal area and deep navigation channels directs most of the currents past the Elizabeth River mouth. This may reduce the impact of James River copper loading on the Elizabeth River (figure 2). Because of this prevalent tidal regime and because of the complexities of copper speciation in an estuarine environment, copper loading was only estimated for the two smaller Elizabeth River and Little Creek sub-watersheds. Since these regions contain the majority of naval activity in the Hampton Roads, the sub-watershed analysis provides a means to estimate localized impacts of Navy operations relative to civilian copper contributions.

ENVIRONMENTAL DATA SOURCES

The Chesapeake Bay Basinwide Toxics Reduction Strategy Reevaluation Report (Chesapeake Bay Program, 1994) evaluated toxic loadings to Chesapeake Bay waters. Less detailed point source loading estimates were incorporated into the Chesapeake Bay Program loading estimates compared to similar local studies of the Elizabeth River because of the basin level scale and the scope of the Chesapeake Bay Program project (URS Consultants, Inc., 1996).

The Virginia Department of Environmental Quality (VADEQ) has a water quality monitoring network with over 836 monitoring stations covering 78,858 stream kilometers (49,000 miles) and 6,475 km^2 (2,500 mi^2) of estuaries (Virginia Department of Environmental Quality, 1997). However, Mr. Roger Stewart (VADEQ) stated in telephone conversations with SSC San Diego personnel that

much of the past metals data for Virginia are unreliable because of laboratory contamination. A revised clean procedure for metal analysis is currently being incrementally implemented in freshwater systems studies to be followed by marine monitoring after 2000.

The U.S. Army Corps of Engineers (USACOE) has sediment copper data available for the Norfolk area because of navigation channel dredging operations. However, in many cases, most of these values are no longer applicable following subsequent dredging and removal of sediments. The only current copper data with adequate quality control are from the Atlantic Division, Naval Facilities Engineering Command (LANDIV)-sponsored water-effects and chemical translator study conducted from 1995 to 1996[*†]. Ambient copper measurements were made adjacent to naval facilities in the region and are summarized in table 1.

Table 1. Average (n=2) ambient water concentrations of copper adjacent to U.S. Navy facilities in Norfolk, VA.

	Copper Concentration by site (µg/L)							
Cu Speciation	Willoughby Bay	Naval Base Norfolk	Craney Creek	Craney Isl Oily WWD	Norfolk Naval Shipyard	Mason Creek	Busch Creek	Little Creek
Total	1.30	1.30	2.65	2.20	4.12	1.37	3.89	1.94
Dissolved	1.12	1.16	1.68	1.96	3.81	1.10	3.61	1.44

NORFOLK AND LITTLE CREEK COPPER LOAD

Dissolved copper load to the Norfolk/Elizabeth River area was estimated to be 26,284 kilograms per year (figure 3). Navy hull leachate was the largest copper source at 41% of the total load. The second and third highest load sources were Navy Other Ship discharges at 24%, and Civilian Transit Discharges (i.e., commercial vessel traffic) at 18%. Dissolved copper load to Little Creek is estimated to be 4,962 kilograms per year (figure 4). Navy hull leachate comprised 48% of the total load. Of note is the greater impact that civilian boat hull leachate has on copper loading to this basin (25%). Navy Other Ship Discharges was the third-most-significant copper source category at 24%.

---

[*] Atlantic Division, Naval Facilities Engineering Command. 1993. Ambient copper water concentrations for eight stations. Norfolk, VA.

[†] CH2M Hill, Inc. An integrated approach to obtaining optimal discharge permits. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, VA. Detroit, MI.

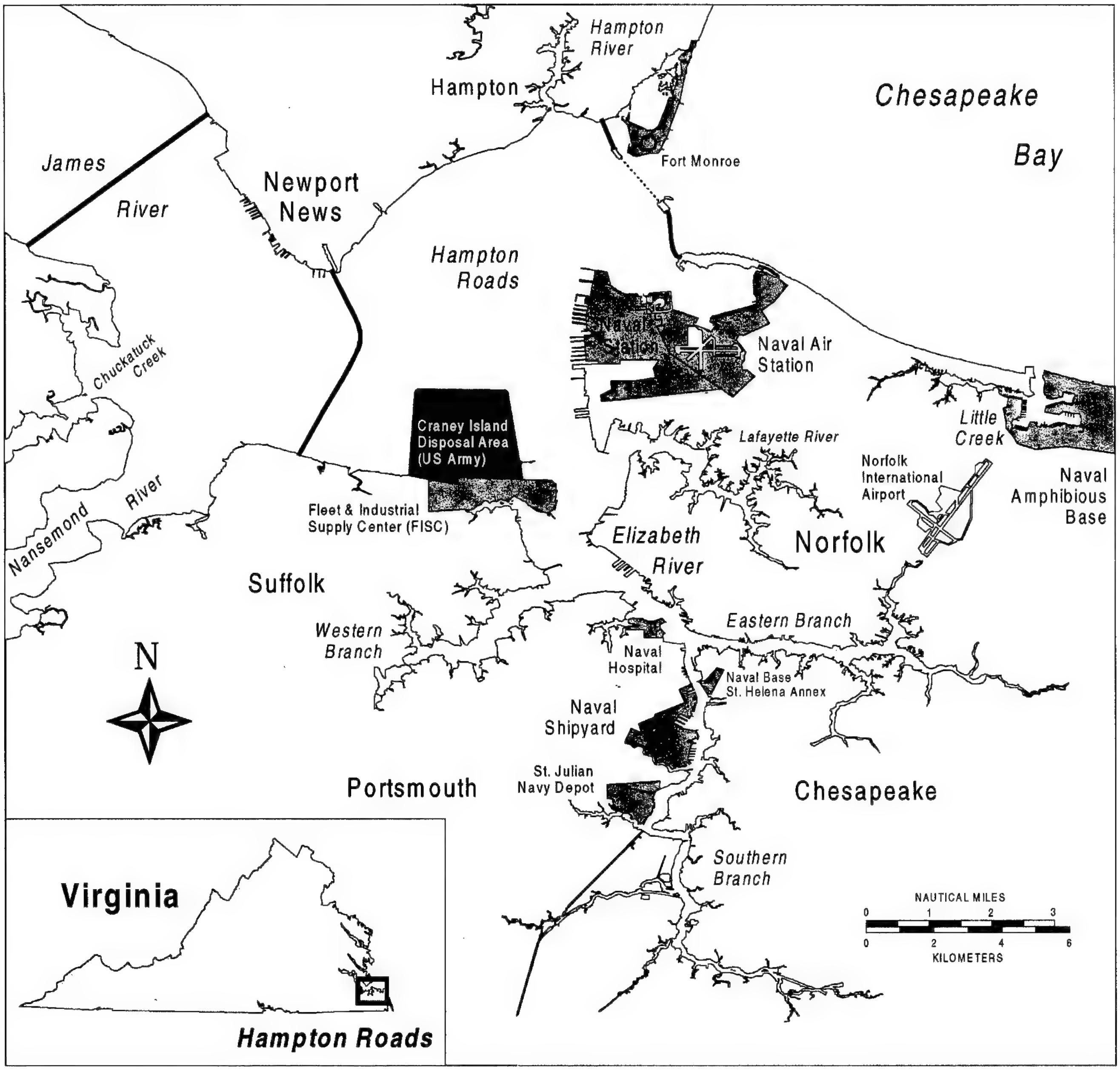


Figure 1. Hampton Roads, VA, showing Elizabeth River drainage, Little Creek drainage, and COMNAVBASE Norfolk facilities.

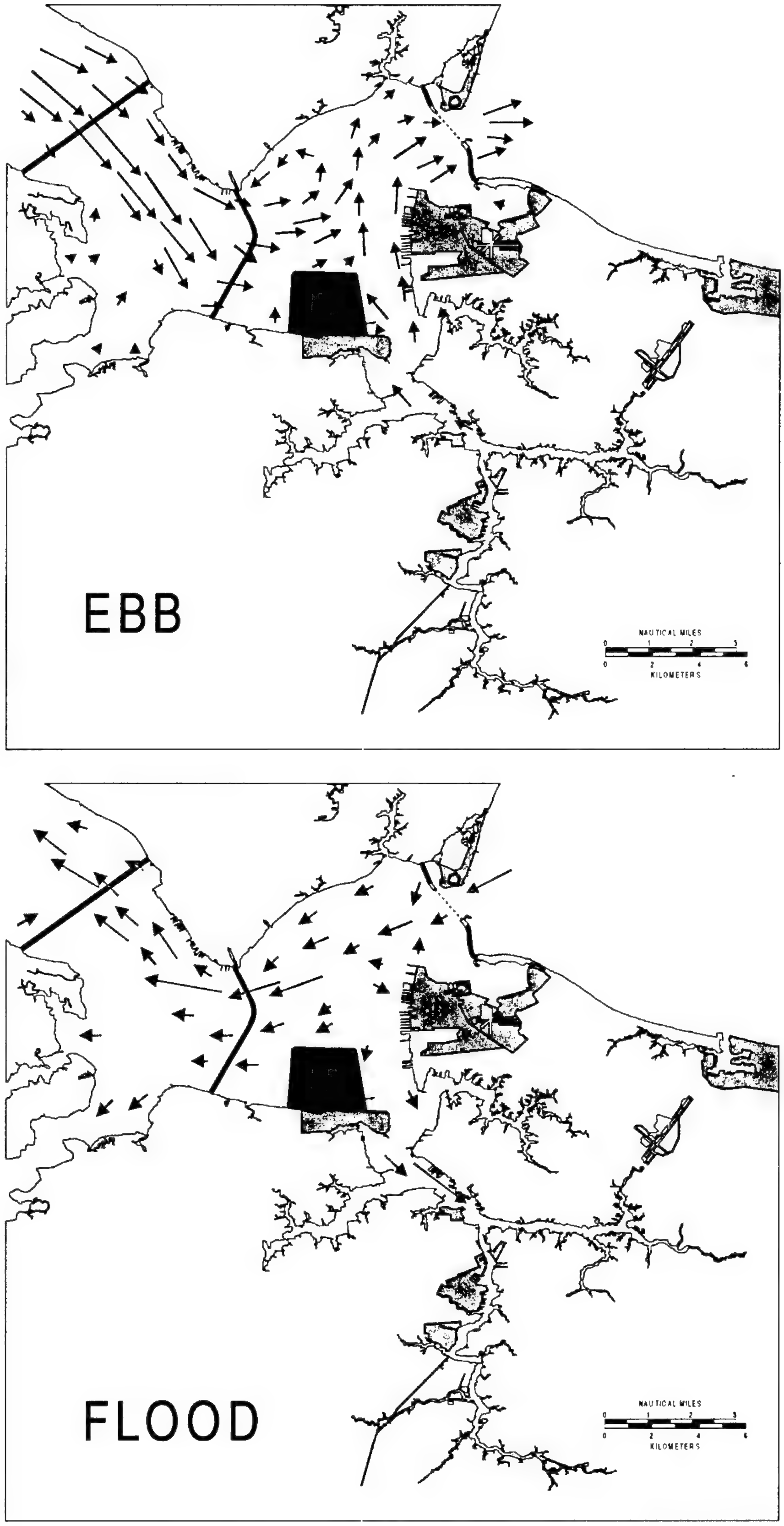
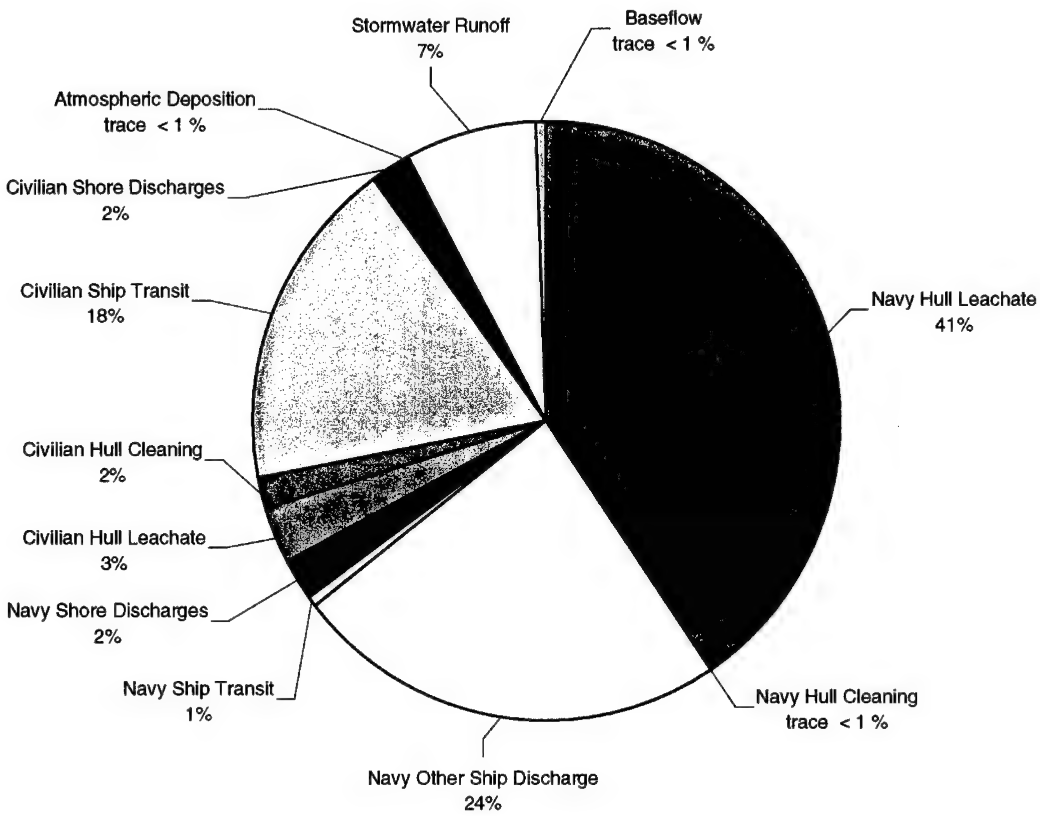
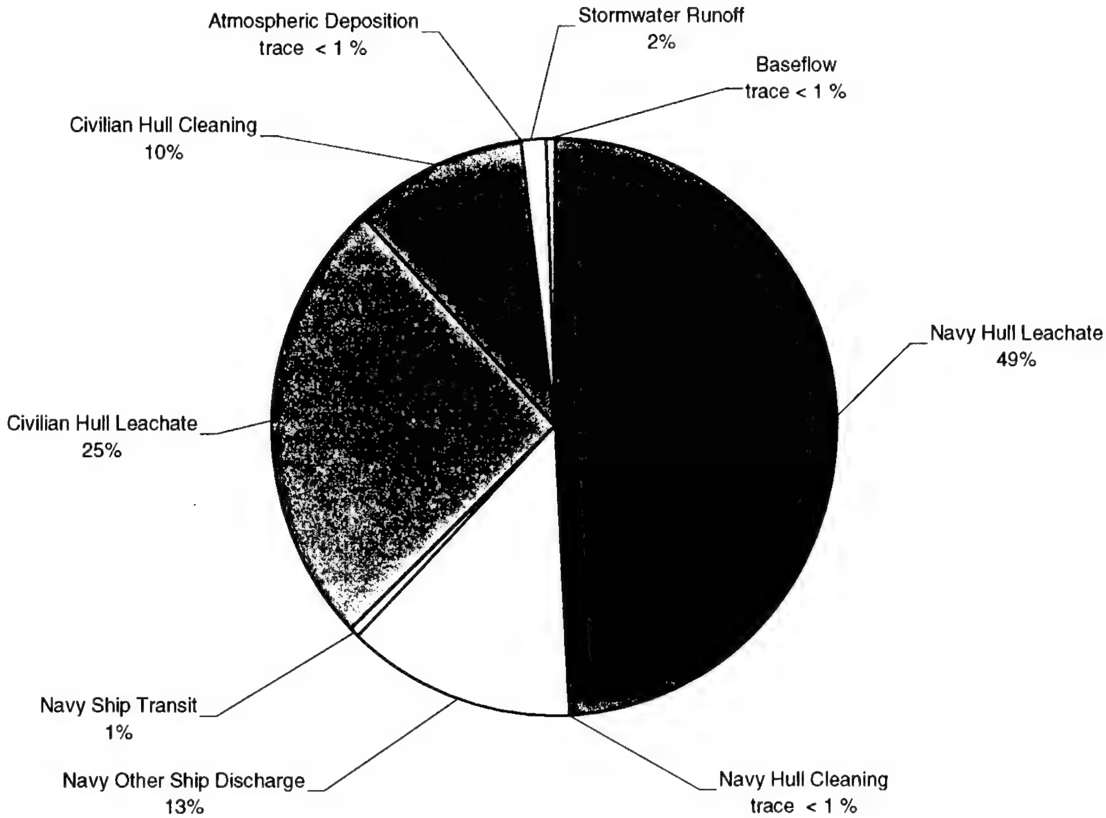


Figure 2. Tidally averaged residual current for Hampton Roads (source: Shen, Boon, & Sisson, 1997).



Source	Annual Dissolved Copper Discharge (kg/yr)
Navy Hull Leachate	10,672
Navy Hull Cleaning	23
Navy Other Ship Discharges	6,250
Navy Ship Discharges in transit	163
Navy Shore Discharges	559
Civilian Small Boat Hull Leachate	823
Civilian Small Boat Hull Cleaning	406
Civilian Ship Transit/Hull Leachate	4,767
Civilian Shore Discharges	533
Atmospheric Deposition	27
Stormwater Runoff	1,962
Baseflow (watershed baseflow)	117
TOTAL:	26,302

Figure 3. Relative source percentages of copper loading to Norfolk, VA.



Source	Annual Dissolved Copper Discharge (kg/yr)
Navy Hull Leachate	2,438
Navy Hull Cleaning	4
Navy Other Ship Discharges	642
Navy Ship Transit Discharges	35
Navy Shore Discharges	N/A
Civilian Small Boat Hull Leachate	1,251
Civilian Small Boat Hull Cleaning	492
Civilian Ship Transit/Hull Leachate	N/A
Civilian Shore Discharges	N/A
Atmospheric Deposition	1
Stormwater Runoff	76
Baseflow (watershed baseflow)	23
TOTAL:	4,962

Figure 4. Relative source percentage of copper loading to Little Creek, VA.

NORFOLK SITE-SPECIFIC LOADING ASSUMPTIONS

Figures 5 and 6 show potential copper loading sites for the Elizabeth River.

Navy Hull Leachate and Vessel Discharges

Naval Station Norfolk (NAVSTA) (figure 5), located at the mouth of Elizabeth River adjacent to the open waters of Hampton Roads, currently represents one of the largest naval bases in the world and is homeport to the majority of aircraft carriers, surface ships, and submarines in the Atlantic Fleet. Over 81 surface ships, submarines, and service craft have been identified as officially homeported at NAVSTA Norfolk
(Naval Sea Systems Command Shipbuilding Support Office, 1998; U.S. Navy, 1998).

NAVSTA vessel dissolved copper loading:

Pierside and In-transit		
Hull Leachate:	9,670	kg/yr
Seawater Cooling:	5,719	kg/yr
Firemain Discharge:	471	kg/yr
Non-oily Waste Discharge: (data for aircraft carriers only)	105	kg/yr
In-transit only		
Graywater Discharge:	11	kg/yr
Total:	15,976	kg/yr

Figure 5. Aerial view of Naval Station Norfolk (north-to-south) showing five carriers and other major surface ships in port.

There are also 11 Military Sealift Command (MSC) vessels homeported in Norfolk. In many Navy ports, MSC vessels typically berth at multiple locations within a given harbor based on berth availability and operational necessity. For the purpose of these calculations, the Norfolk MSC ships were arbitrarily assigned to the Fleet Industrial Supply Center (FISC), Norfolk, located near the base of the Craney Island disposal area at the western mouth of the Elizabeth River. MSC vessels were observed berthing at FISC during a July 1998 site visit, but the distribution of homeported MSC vessels needs to be determined.

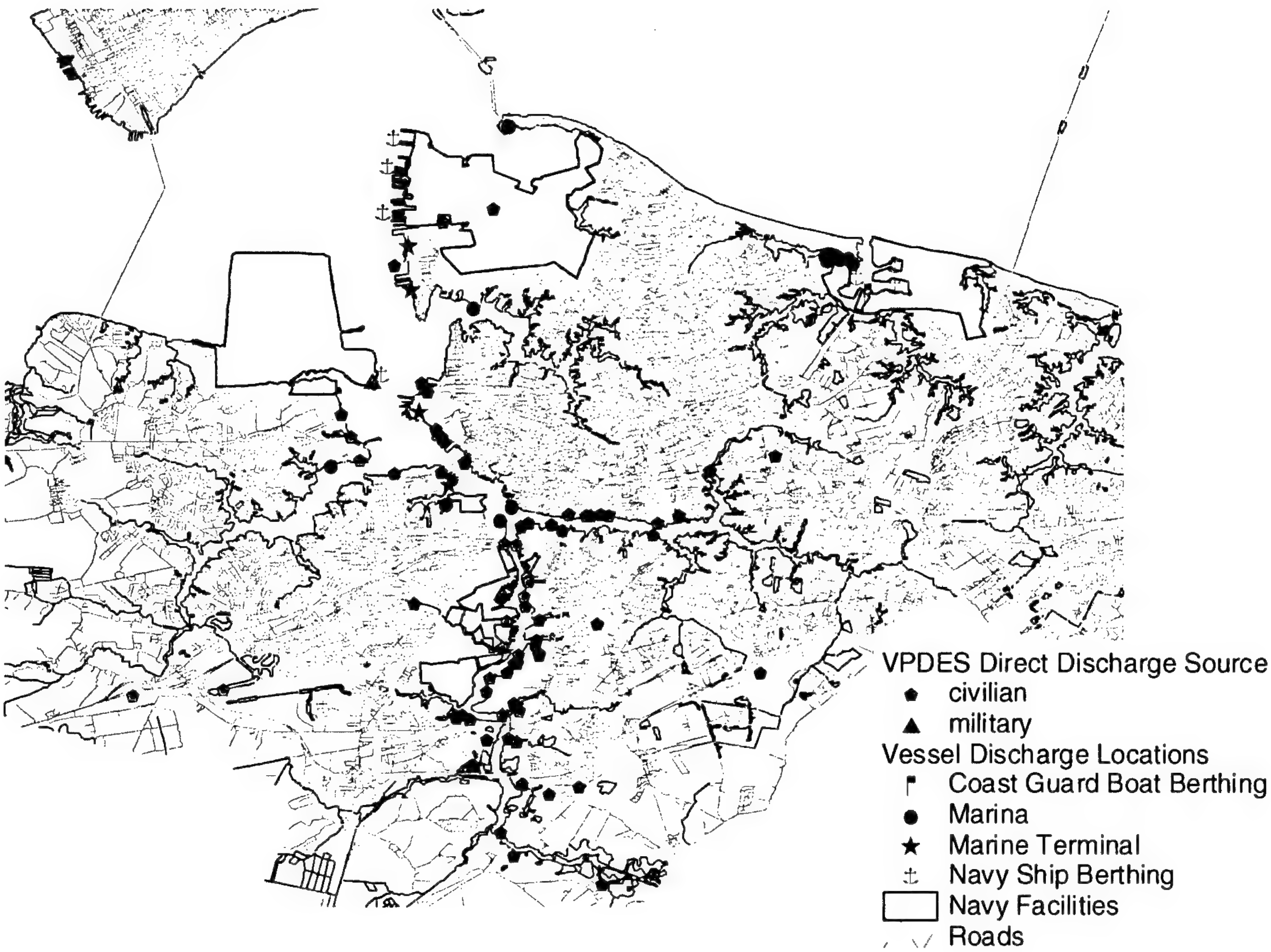


Figure 6. Potential copper release sites for Elizabeth River and Little Creek areas.

MSC vessel dissolved copper loading:

Pierside and In-transit		
Hull Leachate:	755	kg/yr
Seawater Cooling:	107	kg/yr
Firemain Discharge:	0	kg/yr
Non-oily Waste Discharge:	N/A	kg/yr
(data for aircraft carriers only)		
In-transit only		
Graywater Discharge:	0	kg/yr
Total:	862	kg/yr

The Naval Inactive Ship Maintenance Facility, Portsmouth (NISMF) has 24 vessels held in Reserve status or awaiting final deposition following active duty decommissioning. As is the case with all ships in lay-up or disposal status, cooling, firemain, and other shipboard systems are not operational. As detailed in appendix A, underwater hull coatings are not maintained on these vessels and this warrants a lower leach rate in the loading calculation.

NISMF vessel dissolved copper loading:

Pierside and In-transit		
Hull Leachate:	246	kg/yr

Navy Hull Cleaning

Analysis of the Naval Sea Systems Command (NAVSEA) hull cleaning database for 1994 to 1997 documented the following annual complete hull cleanings in the Norfolk and Little Creek area:

Year	# full hull cleanings*
1994	20
1995	25
1996	36
1997	23
Four year average:	25

*includes cleanings at both NAVSTA and NAB Little Creek

Only the 1997 cleaning data were used to identify the actual Navy ship cleaned and to apply the hull cleaning formula to the wetted hull area specific to that vessel. With the reduction in fleet size because of ship obsolescence and budget constraints, it was felt that using a recent single year cleaning count vice a multi-year average was more appropriate, and that this would be a better indicator of future hull cleaning loads. Twenty of the 23 full hull cleanings for 1997 occurred at NAVSTA (18 surface ships and 2 submarines).

U.S. Navy hull cleaning dissolved copper load:

Hull Cleaning:	23	kg/year

Direct Shore Discharges

URS Consultants, Inc. (1996) conducted a detailed analysis of direct discharges and potential metal loading to the Elizabeth River. Since URS Consultants, Inc. reviewed site-specific Discharge Monitoring Reports (DMRs) and determined detailed flow-weighted averages for each facility, URS Consultants, Inc. loading estimates were incorporated into this study. There were 75 reported Virginia Pollutant Discharge Elimination System (VPDES)-permitted facilities that discharge directly to the Elizabeth River. These include two municipal sewage treatment plants, the Army Base Plant, and the Virginia Initiative Plant, all operated by the Hampton Roads Sanitation District (HRSD). Combined daily flow for these plants is 52 MGD. Other major dischargers include Norfolk Naval Base, Norfolk Naval Shipyard, Craney Island Fuel Terminal, Atlantic Wood, Virginia Power, and Hoechst Celanese with a combined flow of 3 MGD. Minor dischargers include 63 facilities with a combined flow of 3 MGD[‡]. One significant direct discharge not quantified by SSC San Diego is cooling water flow. The Elizabeth River Point Source Team reported 400 MGD in cooling water discharge primarily from the Virginia power facility. Lack of information on outflow copper concentrations precludes estimating copper loading from this source.

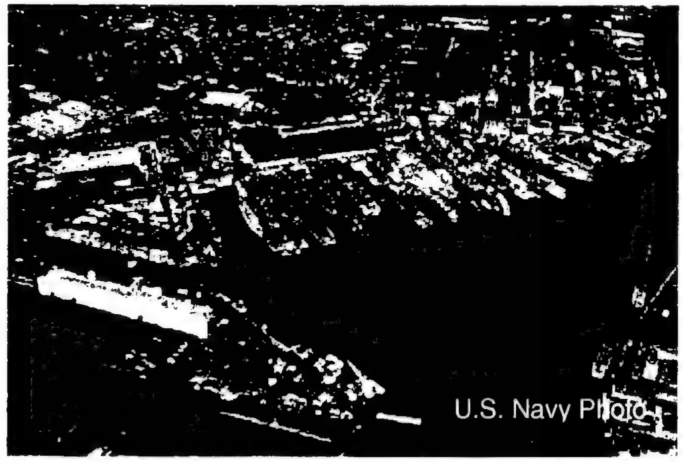


Figure 7. Norfolk Naval Shipyard along the southern branch of the Elizabeth River.

Following conversion of URS Consultants, Inc. loading estimates from total to dissolved using the EPA conversion factor, dissolved copper load to the Elizabeth River was estimated to be 1,051 kg/yr. Norfolk Naval Shipyard (figure 7) was the largest single contributor of copper at 518 kg/yr or 49% of the total load. United States Environmental Protection Agency (USEPA) BASINS v2 data provided an estimated copper loading of 41 kg/yr for NAVSTA, which was not included in the original analysis conducted by URS Consultants, Inc.

Direct shore-based discharge dissolved copper load:

Navy Permitted Discharges:	559	kg/yr
Civilian Permitted Discharges:	533	kg/yr
Total:	1,092	

[‡] Elizabeth River Point Source Team. 1994. The significance Point Source pollutant loads to the Elizabeth River system, unpublished manuscript.

Civilian Pleasure Craft and Small Boats

Seven marinas with 788 in-water pleasure craft were identified through a telephone survey of the Elizabeth River area in July 1998 (table 2).

Table 2. Marinas queried in Norfolk, VA area regarding pleasure boat counts.

Sub-Region	Marina Name	# of boats	Total # of slips	Avg. length (m)
Willoughby Bay	Willoughby Bay Marina	55	65	9.1
	Willoughby Harbor	300	300	10.7
Lafayette River	Norfolk Yacht and Country Club	80	*	7.6
Elizabeth River—Western Branch	Nautical Boats	90	*	7.6
Elizabeth River—Eastern Branch	Waterside Marina	30	*	10.7
	Tidewater Yacht Marina	200	300	7.6
Elizabeth River-Scotts Creek	Scotts Creek Marina	0	*	10.7
	Portsmouth Boating	33	33	10.7

* = unknown or not available

Copper loading from two additional civilian vessel copper sources cannot be estimated. One is non-marina small boat berthing, and the other is transit traffic through the Intercoastal Waterway (ICW). Multiple neighborhood moorings and docks adjacent to waterfront residences were not accounted for in the marina survey. Single or multiple boats are often moored in non-marina locations along the many small creeks, streams, and river branches common to the Chesapeake Bay. Although the State of Virginia maintains records of boat registration, SSC San Diego has not found an agency that maintains exact in-water boat counts by location.

The Elizabeth River serves as a major artery in the ICW, a series of waterways and canals extending the length of the East Coast from Maine to Florida. SSC San Diego does not currently have traffic estimates for ICW transits. If traffic counts become available, then by using an assumed average boat length and average transit time, copper input from this source can be estimated.

Civilian pleasure craft hull leachate and hull cleaning dissolved copper load:

Anti-fouling Paint Hull Leachate:	823	kg/yr
Hull cleaning operations:	406	kg/yr
Total:	1,229	

Civilian Commercial Ship Traffic

The ports of Norfolk and Portsmouth are major regional centers of commercial shipping with the second largest cargo volume on the East Coast, after New York City. With almost 62 million short

tons of cargo traded in 1996, the port of Norfolk was the second busiest seaport on the East Coast after New York City (Virginia Port Authority, 1998).

The Virginia Port Authority operates two large-scale marine terminals on the Elizabeth River: the Portsmouth Marine Terminal and the NIT-Norfolk International Marine Terminal. Additionally, two other private company terminals on the Elizabeth River include the LPD-Lambert's Point Docks and the ERT-Elizabeth River Terminals (Virginia Port Authority, 1998).

The U.S. Coast Guard Marine Safety Office, Norfolk, estimated that approximately 3,200 vessels per year berth at one of four marine terminals located in the Elizabeth River. The typical duration of their stay is short, about 1 to 3 days.

Many civilian tanker and container vessels may have tributyltin (TBT) anti-fouling hull coatings vice copper paint, since most service work on these ships is done overseas where TBT application may be less strictly regulated. However, since TBT coatings often have copper as a co-biocide and quantifiable information on paint type applied is not available, the NAVSEA copper paint leach rate was used to calculate potential copper loading from hull leachate. An average container ship dimension was used to derive a typical wetted hull surface which was, in turn, multiplied by the number of visiting vessels and duration of stay. A residence time of 2 days was used.

Civilian commercial ship traffic dissolved copper load:

Anti-fouling Paint Hull Leachate:	4,767	kg/yr

Stormwater

There are officially three United States Geological Survey (USGS)-designated watersheds that drain to Hampton Roads and the lower Chesapeake Bay. These are the Lower James, Hampton Roads, and Lynnhaven watersheds. SSC San Diego defined the Little Creek sub-watershed from the Lynnhaven watershed using USEPA BASINS v 2 Geophysical Iinformatio System data (figure 8). The Fall Line is the furthermost reach within a river influenced by tidal activity, and serves as the boundary between the Upper and Lower James River watersheds. Although not factored into the copper loading presented in this study, the Chesapeake Bay Program has estimated an "Above Fall Line" James River (i.e., the USGS Upper James River watershed) annual copper load of approximately 13,500 kg/yr, and a "Below Fall Line" (i.e., Lower James River watershed) annual copper load of approximately 5,000 kg/yr (Chesapeake Bay Program, 1994). Because of the extensive drainage network of the Upper James River, the Above Fall Line area covers much of southern Virginia.

The Elizabeth River sub-watershed and Little Creek sub-watershed, as designated by SSC San Diego, were modeled to gage the relative impact of local land use on potential stormwater copper load. As detailed in figure 1, the copper loading from the James River were thought to be minimum because of the prevailing tidal regime that may inhibit entrained copper from entering the Elizabeth River (Shen et al., 1997).

Elizabeth River Sub-watershed Land Use. The total area within the Elizabeth River sub-watershed is 559 km^2 (137,967 acres). The largest land use category was residential (32%) followed by water (16%) and forest (15%). Industrialized land use comprised only 2% of the total area, but was centrally located along the Elizabeth River and the its southern branch (figure 9, table 3).

Table 3. USEPA BASINS land use categories for the Elizabeth River sub-watershed and the associated composite category used by SSC San Diego.

Land Use Category Used	Original USEPA BASINS v. 2 Land Use Classification	Area (km^2)	Area (acres)	Total (%)
Residential	Residential	178	44,020	32
Commercial	Commercial and Services;	65	16,038	13
	Other Urban Or Built-Up	7	1,785	
Industrial	Industrial;	10	2,348	2
	Indust. & Commercial Complexes	3	882	
Transportation	Trans, Comm, Util	29	7,158	5
Agriculture	Cropland and Pasture	74	18,195	13
Forest	Deciduous Forest Land;	7	1,675	15
	Evergreen Forest Land;	19	4,598	
	Mixed Forest Land;	41	10,178	
	Forested Wetlands	20	4,825	
Water	Streams and Canals;	30	7,501	16
	Lakes;	0.5	101	
	Reservoirs;	2	565	
	Bays and Estuaries	56	13,844	
Open / Parks	Strip Mines;	1	283	3
	Transitional Area;	16	3,967	
	Unclassified	0.02	4	
	Total	559	137,967	

Even Mean Concentrations (EMC). URS Consultants, Inc. (1996) reported the results of regional stormwater monitoring for several Virginia cities (table 4). SSC San Diego used the geometric mean of these EMCs by land use category for our modeling efforts. Since multi-family land use data were not available for all three of the harbors under review, single-family and multi-family values were combined to generate a single residential EMC. No information was available for regional EMCs for roads and streets. Therefore, the road EMC was taken from a Federal Highway Administration study that reported a highway EMC derived from national data (Federal Highway Administration, 1990). Until regional road EMCs are derived for the Hampton Roads area, it was felt that the Federal Highway Administration study provided a reasonable substitute. A separate land use category for "Forest" was developed specifically for Norfolk because of large areas of undeveloped forest common to this region. Schueler (1987) reported an EMC for a northern Virginia hardwood forest below analytical detection limits. However, to provide what is possibly an overly conservative estimate for this study, an EMC for forest land use was derived by taking the lowest regional EMC (agricultural/open land use EMC of 0.0080 mg/L from Chesapeake, which has large rural areas) and dividing by one-half to represent a "background contribution."

Table 4. EMCs from southeastern Virginia city monitoring programs (URS Consultants, Inc., 1996).

	Copper Concentration, Total (mg/L)							
City	Single Family Residential	Multi-family Residential	Commercial	Industrial	Agricultural	Open	Roads	Forest
VA Beach	0.00720	0.01113	0.01980	0.00720	0.01760	0.01760		
Portsmouth	0.00623	0.00847	0.01550	0.01315	0.01760	0.01760		
Norfolk	0.01900	0.01793	0.02600	0.01315	0.01760	0.01760		
Chesapeake	0.00800	0.00800	0.00800	0.00800	0.00800	0.00800		
	Geometric Mean	0.00990 *	0.01590	0.00999	0.01445	0.01445	0.03111	0.004

* composed of geometric mean of single-family and multi-family residential EMCs

Annual rainfall. Annual rainfall from the Norfolk Airport for the years 1962 to 1991 is 114 cm (45 inches) (URS Consultants, Inc., 1996).

Perviousness. Table 5 lists the percent imperviousness by land use category used in the modeling formula.

Table 5. Percent imperviousness by land use categories for southeastern Virginia cities (URS Consultants, Inc., 1996).

	% Impervious by Land Use							
City	Single Family Residential	Multi-family Residential	Commercial	Industrial	Agricultural	Open	Roads	Forest
VA Beach	25.0	50.0	71.0	81.0	5.0	10.0		
Portsmouth	25.0	50.0	45.0	80.0	5.0	13.0		
Norfolk	25.0	63.0	43.0	80.0	5.0	10.0		
Chesapeake	24.0	50.0	50.0	73.0	5.0	8.0		
	Geometric Means	36.2 *	51.2	78.4	5.0	10.1	90.0	5.0

* composed of geometric mean of single-family and multi-family residential imperviousness

The Simple Stormwater model was calculated with the above terms and the final value converted from total-to-dissolved copper by the USEPA translator (United States Environmental Protection Agency, 1995). The final loading results for stormwater and baseflow runoff for the Elizabeth River are presented below.

Elizabeth River Sub-Watershed Stormwater Runoff dissolved copper load:

Elizabeth River Sub-watershed Stormwater:	1,962	kg/yr
Sub-watershed Baseflow:	117	kg/yr
Total:	2,079	

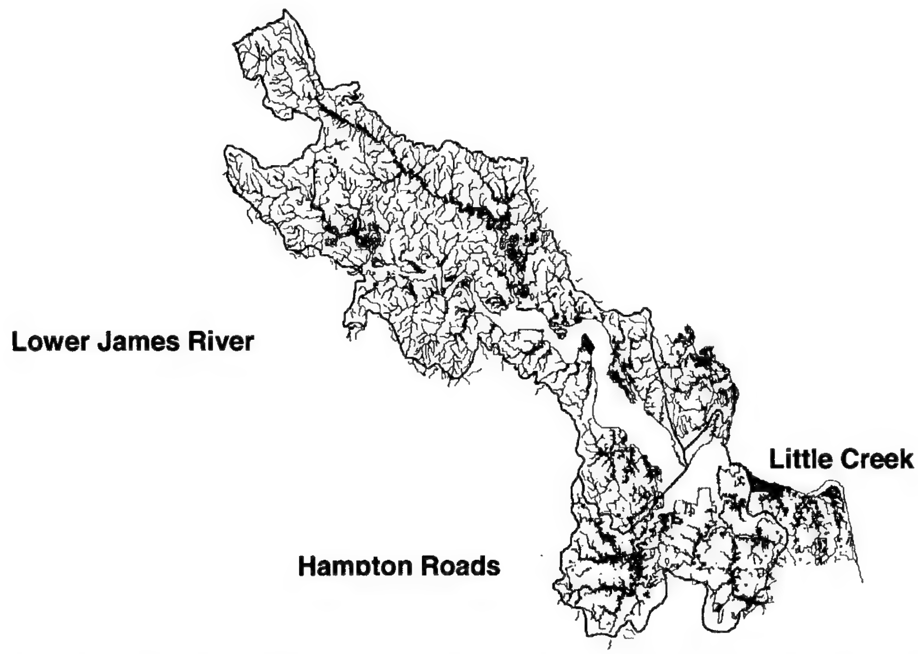


Figure 8. United States Geological Survey-designated watersheds within James River drainage basin and SSC San Diego-designated Little Creek sub-watershed.

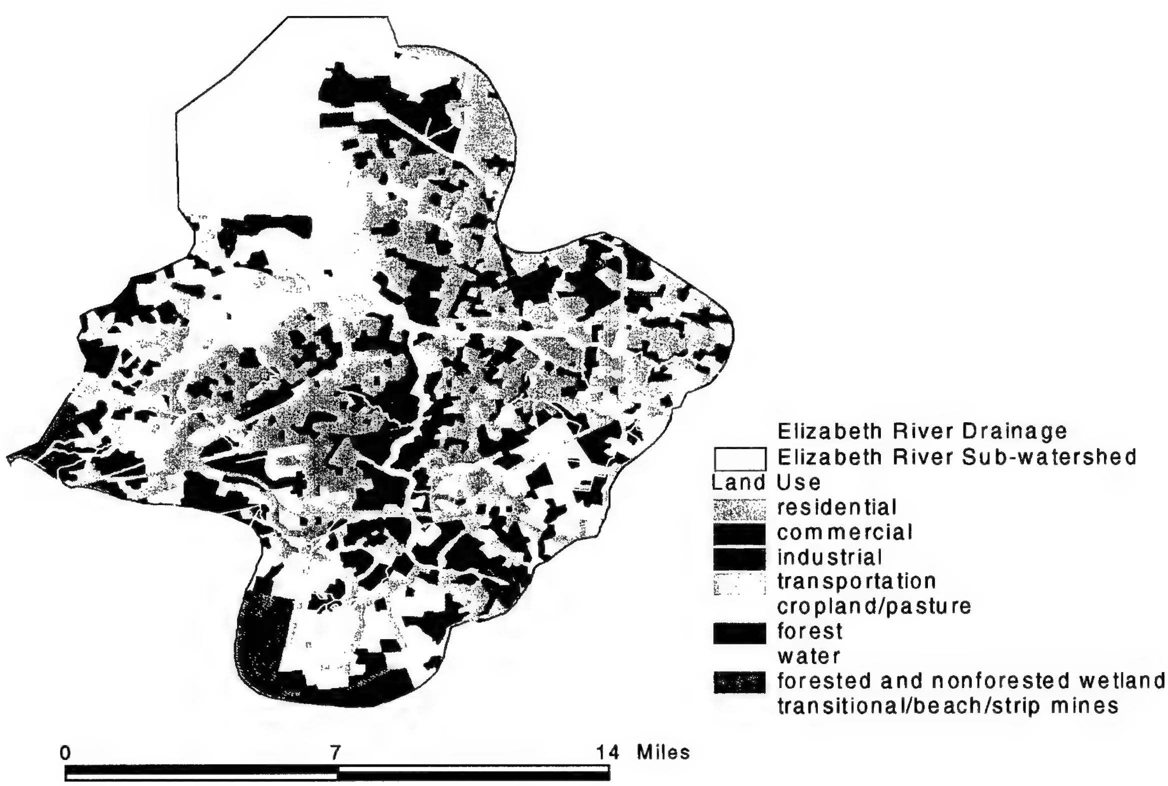


Figure 9. Land use as defined by the USEPA (BASINS v2.0) for the Elizabeth River sub-watershed (one of two sub-watersheds comprising the Hampton Roads watershed HUC: 0208208).

Atmospheric Deposition

The United States Environmental Protection Agency (1997) presented results of monitoring studies for air deposition of multiple contaminants, including copper, to the Chesapeake Bay. The air shed influencing the Bay is significantly larger that the Chesapeake Bay watershed (figure 10). Copper loading for the surface area of the entire Bay was reported as 9,200 kg/year. To estimate potential air shed deposition to the Elizabeth River sub-watershed aquatic area, this bay-wide copper load was divided by the Chesapeake Bay surface area (30,800 km^2 or 11,892 mi^2) to obtain a load of 0.299 kg/ km^2-yr. USEPA BASINS v2 GIS software and data sets for the Elizabeth River sub-watershed listed a total water area of 89 km^2 (34.4 mi^2). It is assumed that any deposition to land areas was accounted for in the stormwater runoff.

This approach to atmospheric deposition is a crude localization based on basin-wide information that does not factor in the effects of local copper release and deposition specifically within the Elizabeth River sub-watershed. This is because of a lack of site-specific information regarding copper air emissions release and deposition data specifically for the Elizabeth River. Metals do have a relatively short atmospheric lifetime according to Commission for Environmental Cooperation (1997), and will be deposited sooner than some other airborne contaminants.

Atmospheric deposition dissolved copper load:

Atmospheric Deposition:	27	kg/yr

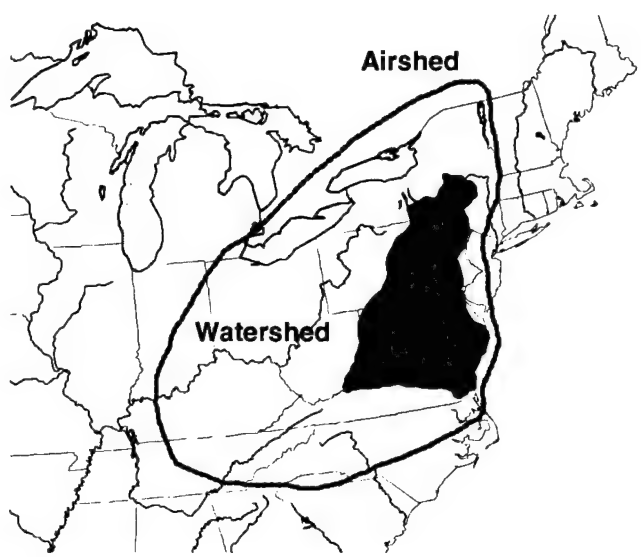


Figure 10. The Chesapeake Bay watershed and air shed (source: United States Environmental Protection Agency, 1997).

LITTLE CREEK SITE-SPECIFIC LOADING ASSUMPTIONS

Navy Hull Leachate and Vessel Discharges

There are 25 surface vessels and 3 service craft homeported in Little Creek, Virginia. This includes three Coast Guard vessels (two 82-ft patrol vessels and one 41-ft utility boat) located at Coast Guard Station Little Creek. There are also 65 assorted Landing Craft attached to Assault Craft Unit Two assigned to Naval Amphibious Base, Little Creek (Naval Amphibious Base, Little Creek, 1998).

The U.S. Navy uses an assortment of landing craft for amphibious operations, and SSC San Diego does not have the current craft distribution for ACU TWO. To quantify the impact of in-water assault craft hull leachate, the LCU 1610 class was used as a "standard" craft type. Naval Sea Systems Command (1997a) provides a list of assault craft inventory for the U.S. Navy and their associated wetted hull area.

Little Creek Vessel dissolved copper load:

Pierside and In-transit		
Hull Leachate:	2,438	kg/yr
Seawater Cooling:	609	kg/yr
Firemain Discharge:	67	kg/yr
Non-oily Waste Discharge:	N/A	
(data for aircraft carriers only)		
In-transit only		
Graywater Discharge:	1	kg/yr
Total:	3,115	

Dissolved copper load by discharge category for Navy berthing sites in Little Creek:

Hull Leachate:	2,438	kg/year
Other Discharges:	642	kg/year
In-transit Discharges:	35	kg/year
Total:	3,115	

Navy Hull Cleaning

Based on analysis of the NAVSEA hull cleaning database for 1997, three ships were cleaned in Little Creek during that year.

Little Creek hull cleaning dissolved copper load:

Hull Cleaning:	4	kg/yr

Direct Shore Discharges

SSC San Diego does not currently have NPDES information for any direct discharges to Little Creek.

Civilian Pleasure Craft and Small Boats

Eight marinas with 956 pleasure craft were reported for Little Creek in the July 1998 telephone survey (table 6, figure 11).

Table 6. Marinas queried in Little Creek, VA area regarding pleasure boat counts.

Marina name	# of boats	Total # of slips	Ave. length (m)
Bay Marina	62	104	9.1
Bay Point Marina	280	318	10.7
Clyde's Marina	44	unk	10.7
Cobbs Marina	20	80	10.7
Cove Marina	151	151	9.1
Cutty Sark Marina	95	100	10.7
Little Creek Marina	115	130	10.7
Tailor's Landing	189	270	10.7

Civilian pleasure craft dissolved copper load:

Anti-fouling Paint Hull Leachate:	1,251	kg/yr
Hull cleaning operations:	492	kg/yr
Total:	1,743	

Civilian Commercial Ship Traffic

No information was available on civilian commercial vessel traffic in Little Creek.

Stormwater

Land Use. Total land within the Little Creek sub-watershed is 17.8 km^2 (4,570 acres) (table 7). The majority of land adjacent to Little Creek, as identified by USEPA BASINS data, is Navy-owned with the largest percent of land use being residential (59%) followed by water (12%) (figure 11).

Table 7. USEPA BASINS land use categories for Little Creek sub-watershed and associated composite category used by SSC San Diego.

Land Use Category Used	Original USEPA BASINS v 2 Land Use Classification	Area (km^2)	Area (acres)	Total (%)
Residential	Residential	11	2,718	59
Commercial	Commercial And Services;	4	1,008	24
	Other Urban Or Built-Up	0.4	87	
Industrial	Industrial; Industrial & Commercial Complexes		0 0	0
Transportation	Trans, Comm, Util	0.4	105	2
Agriculture	Cropland And Pasture		0	0
Forest	Deciduous Forest Land;		0	2
	Evergreen Forest Land;		0	
	Mixed Forest Land;		0	
	Forested Wetlands	0.4	109	
Water	Streams And Canals;	2	542	12
	Lakes;		0	
	Reservoirs;		0	
	Bays And Estuaries	> 0.1	1	
Open / Parks	Strip Mines;		0	0
	Transitional Area;		0	
	Unclassified		0	
	Total	17.8	4,570	

Other Stormwater terms. EMCs, annual rainfall and degree of imperviousness values from the Norfolk model were used for Little Creek as well.

Stormwater and baseflow runoff dissolved copper load:

Little Creek Sub-watershed Stormwater:	76	kg/yr
Sub-watershed Baseflow:	23	kg/yr
Total:	99	

Atmospheric Deposition

The same deposition rate of 0.299 kg/km^2-yr determined previously was used for the Little Creek water area.

Atmospheric deposition dissolved copper load:

Atmospheric Deposition: 1 kg/yr

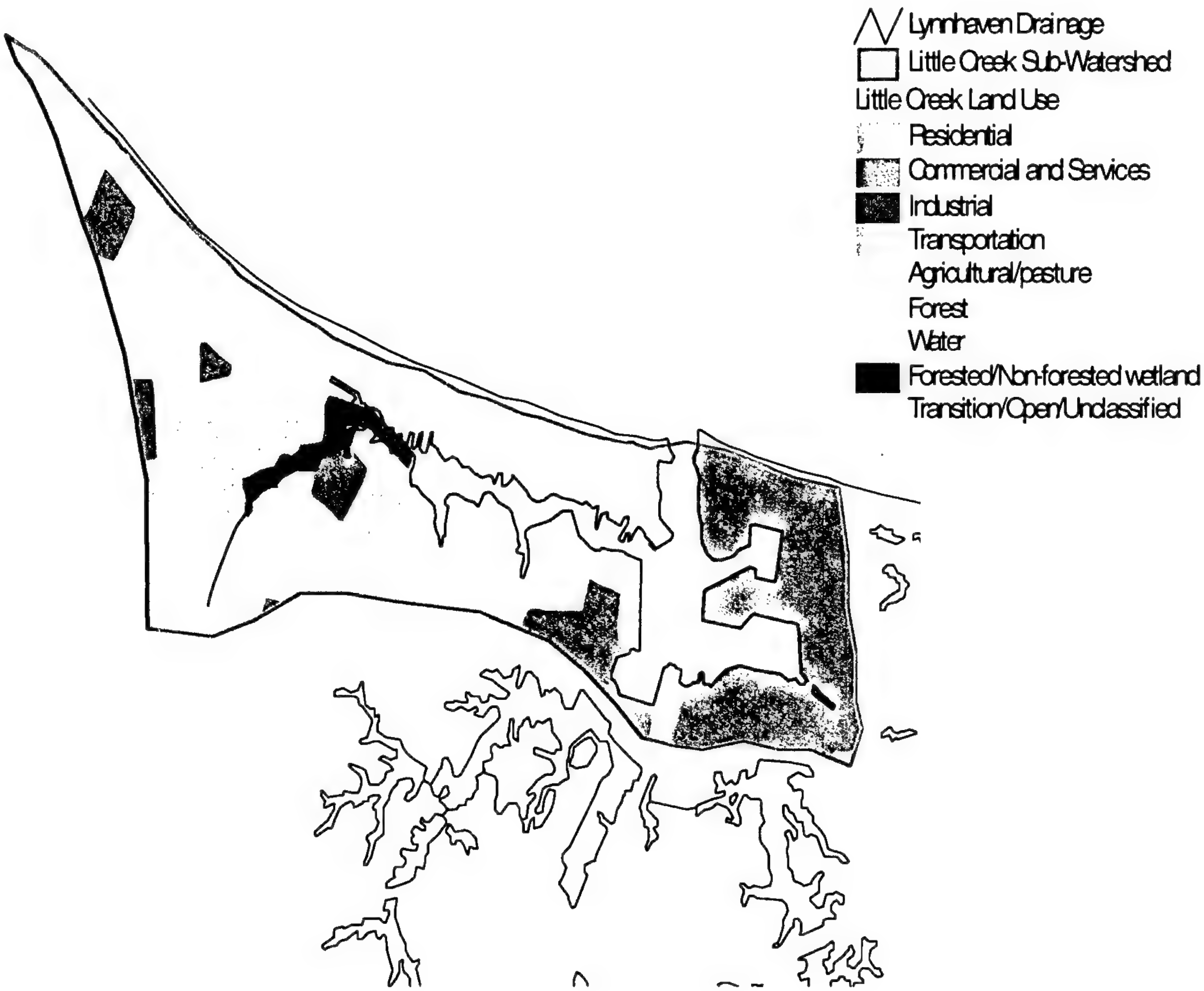


Figure 11. Land use for the SSC San Diego-designated Little Creek sub-watershed.

PEARL HARBOR, HI

Pearl Harbor, a natural estuary on the southern edge of Oahu, is unique from many other industrialized harbors in that the surface waters are entirely under the jurisdiction of the U.S. Navy (Grovhoug, 1992), and dominated by a significant homeport presence of surface ships, submarines, and Inactive/Reserve vessels. A large shore-based infrastructure has developed around the harbor in response to a historical build-up of the area as a major support base for fleet operations (figure 12).

ENVIRONMENTAL DATA SOURCES

Pearl Harbor has been the focus of several past environmental studies and recent projects involving SSC San Diego scientists. Grovhoug (1992) provided the basis for evaluating the history and ecological assessment of the harbor. The Pacific Division, Naval Facilities Engineering Command (PACDIV) recently completed the Phase I sampling of water, sediment, and animal tissue as part of on going Remedial Investigation/Feasibility Study (RI/FS) at Pearl Harbor (Ogden Environmental and Energy Services Company, Inc., 1996). This represents the most current data collection available. Additionally, SSC San Diego conducted an on-site survey in February 1998 to update Pearl Harbor-specific information and locate new sources of receiving water data.

Grovhoug (1992) reported an average water total copper concentration of 2.1 µg/L based on a one-time sampling of nine stations throughout the harbor in 1990. Using a total-to-dissolved ratio of 0.83 promulgated by the United States Environmental Protection Agency (1995), an average dissolved copper concentration of 1.8 µg/L was determined. Ogden (unpublished data) sampled a total of five stations for water quality in 1995 as part of the RI/FS effort (Ogden Environmental and Energy Services Company, Inc., 1996). Results are presented in table 8.

Table 8. Copper water concentrations in Pearl Harbor (Ogden Environmental and Energy Services Company, Inc., unpublished data).

Sampling Location	Concentration (µg/L)	Qualifier
Main Channel: Hickam AF Base Runoff Ditch	*	Non-detect (1.8 µg/L detection
West Loch: Waterfront park on west shore	*	Non-detect (1.8 µg/L detection
Middle Loch: Public access area (north end of (Loch)	*	Non-detect (1.8 µg/L detection
East Loch: Blaisdell Park	3.5	Estimated
East Loch: FLETRAGRU Firefighting Training Area	23.0	Measured
East Loch: FLETRAGRU Firefighting Training Area	6.9	Estimated

Pearl Harbor Naval Shipyard and the Public Works Center, NAVSTA Pearl Harbor, do not possess any long-term water monitoring data for metals. Excess nutrients and traditional water quality parameters (dissolved oxygen, turbidity, and pH) have long been a higher priority environmental and regulatory issue for the region.

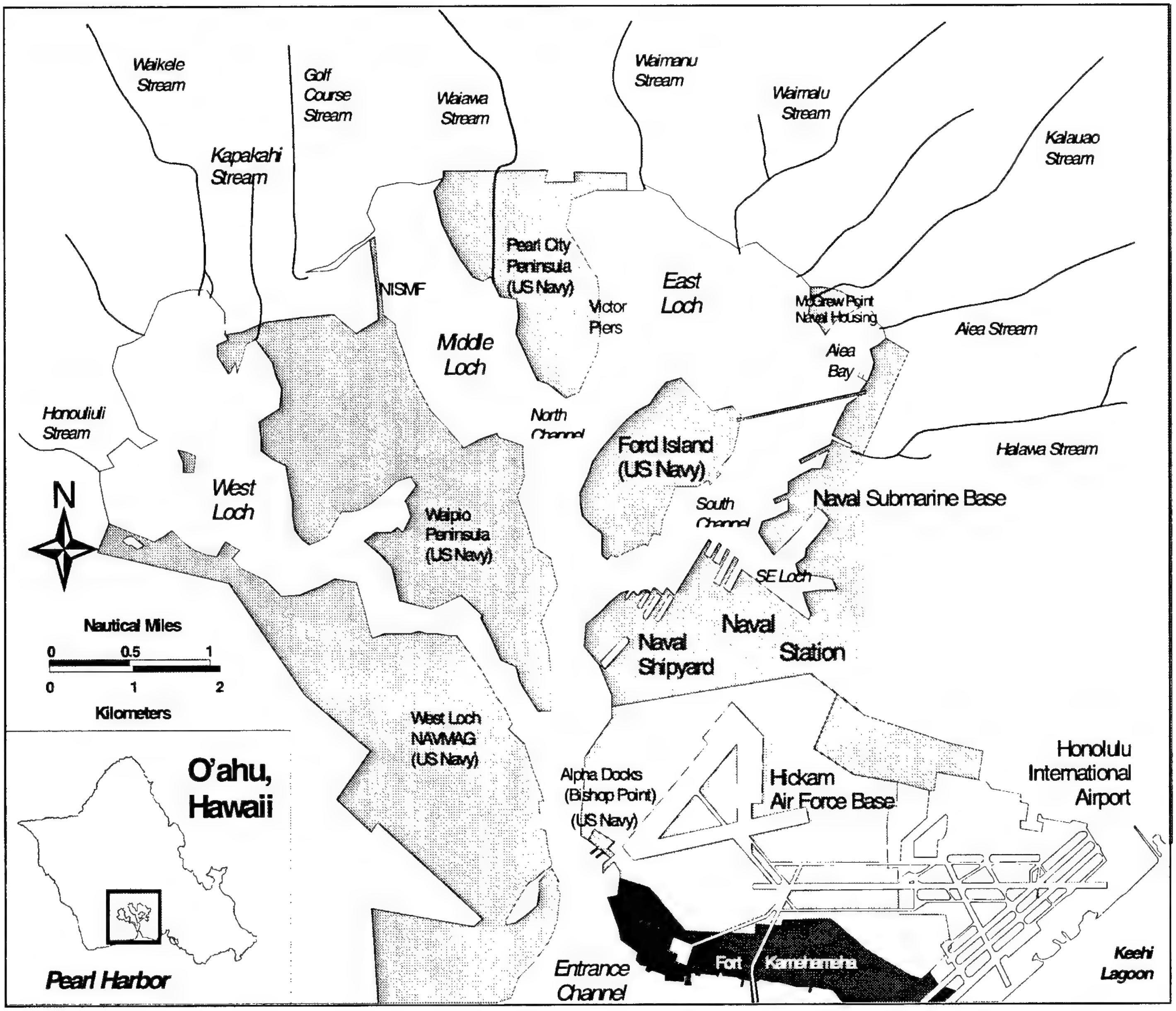
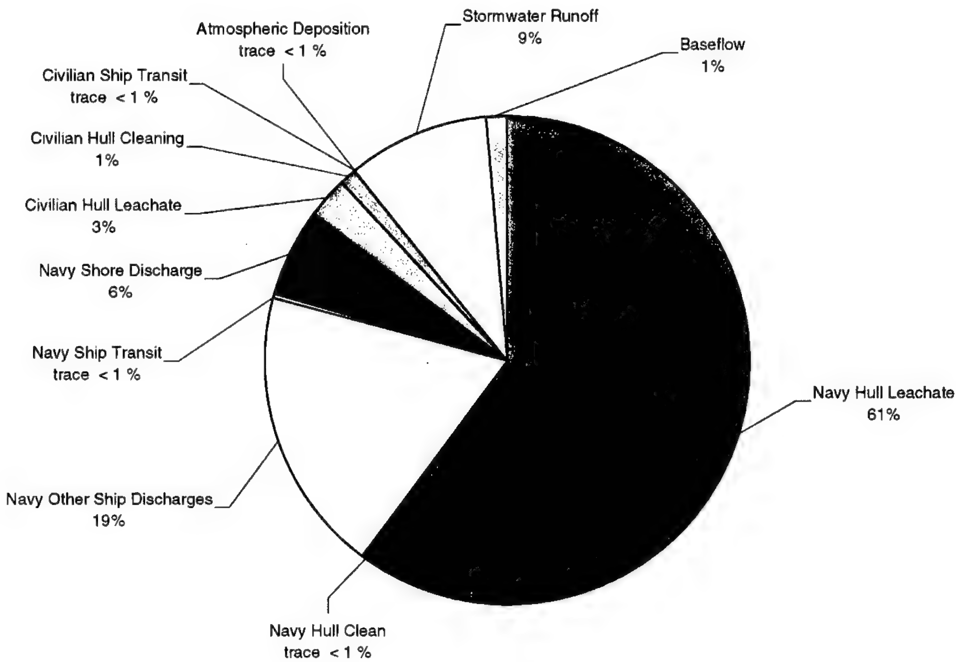


Figure 12. Pearl Harbor, HI, showing stream drainage, COMNAVBASE Pearl Harbor facilities, and other DoD sites.

PEARL HARBOR COPPER LOAD

The Pearl Harbor copper load is estimated at 7,781 kg/yr (figure 13). Navy hull leachate was the most significant copper source, comprising 61% of the total load. This was the single largest percentage loading of any harbor, although the actual amount of copper load is lower when compared to Norfolk and San Diego Bay. Navy Ship Other Discharges was the second most significant source at 19%. These results are not surprising given the almost exclusive use of Pearl Harbor by the Navy. There are few significant civilian copper sources discharging to the harbor.



Source	Annual Dissolved Copper Discharge (kg/yr)
Navy Hull Leachate	4,656
Navy Hull Cleaning	33
Navy Other Ship Discharges	1,479
Navy Ship Transit Discharges	23
Navy Shore Discharges	437
Civilian Small Boat Hull Leachate	224
Civilian Small Boat Hull Cleaning	80
Civilian Ship Transit/Hull Leachate	9
Civilian Shore Discharge	N/A
Atmospheric Deposition	2
Stormwater Runoff	730
Baseflow (watershed baseflow)	108
TOTAL:	7,781

Figure 13. Relative source percentage of copper loading to Pearl Harbor, HI.

PEARL HARBOR SITE-SPECIFIC LOADING ASSUMPTIONS

Figures 14 and 15 present potential copper sources located in Pearl Harbor.

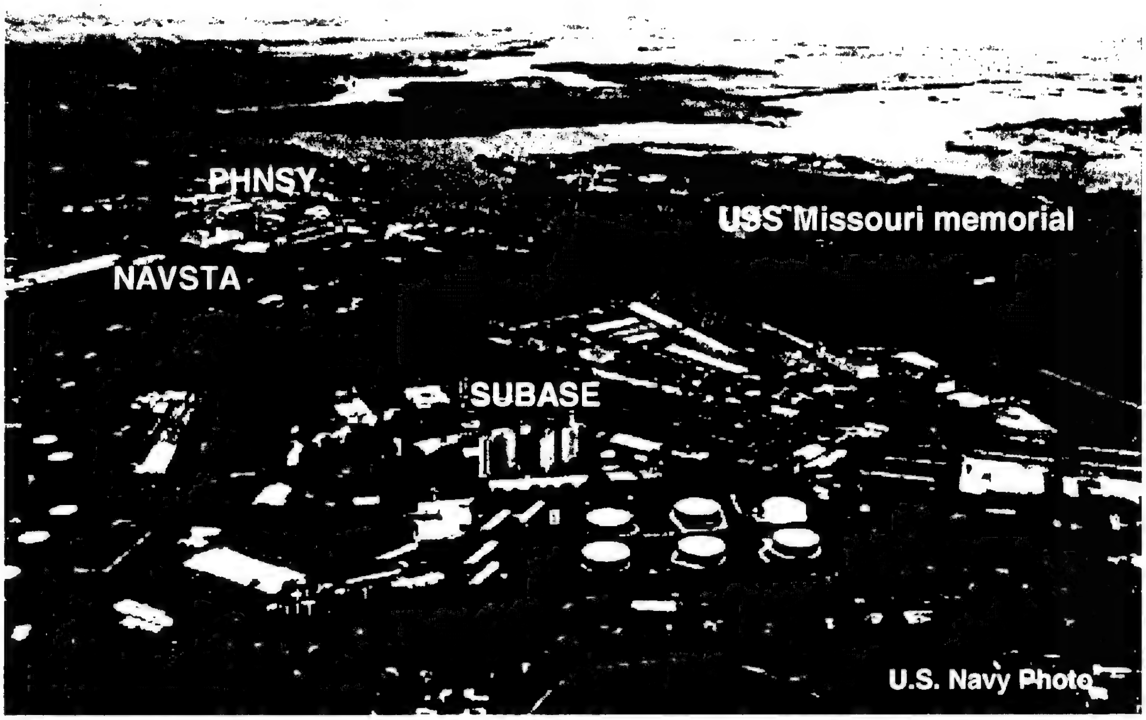


Figure 14. Aerial photo of Naval Base Pearl Harbor (east-to-west) showing (from bottom to top) Southeastern Loch, Middle Loch, West Loch, and the Waianae Mountains.

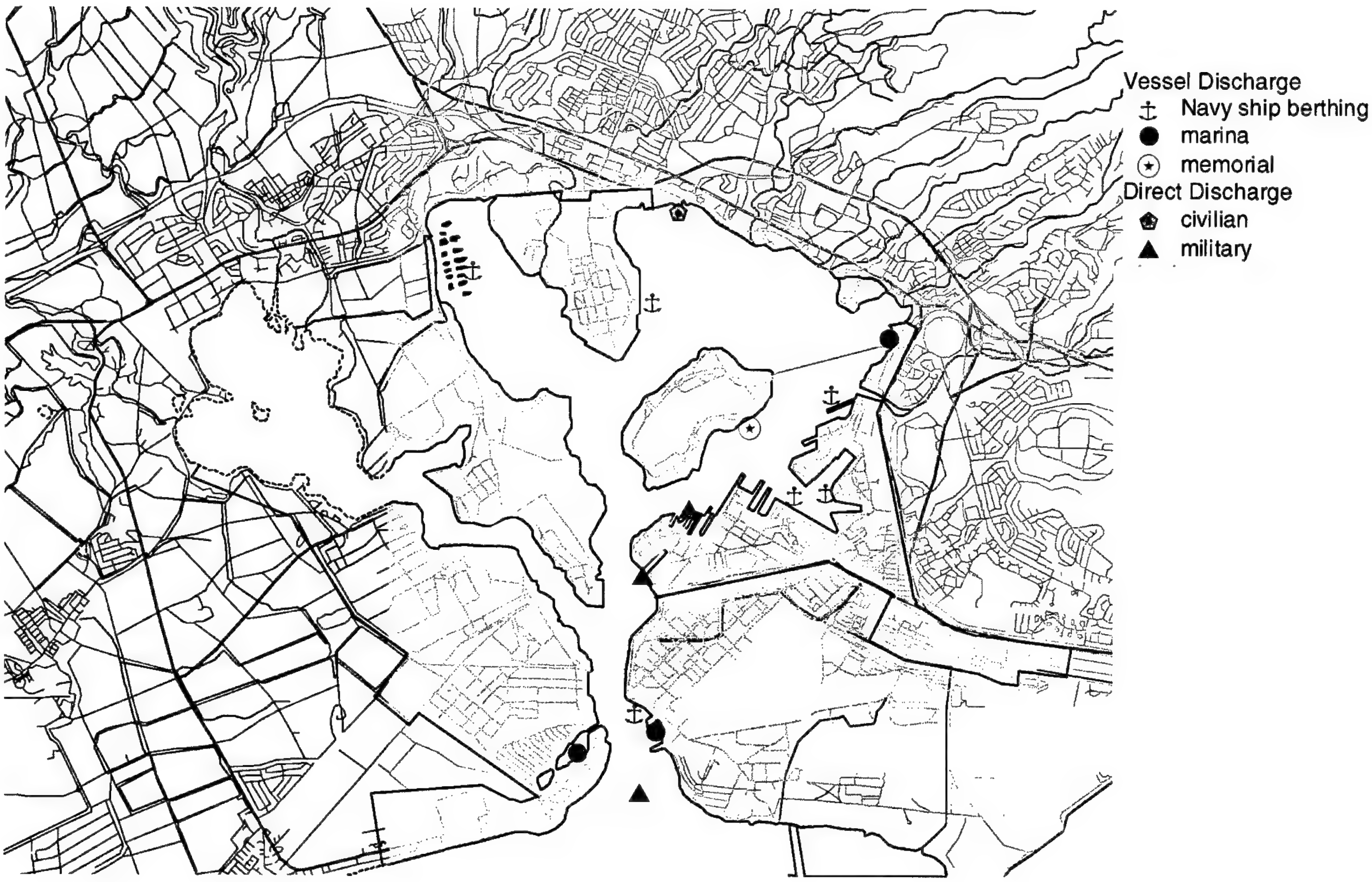


Figure 15. Potential copper release sites for Pearl Harbor, HI.

Navy Hull Leachate and Vessel Discharges

There are three major and two minor naval berthing areas in the Pearl Harbor area. Major berthing areas include Naval Station Pearl Harbor (NAVSTA), Submarine Base Pearl Harbor (SUBASE), and the Naval Inactive Ship Maintenance Facility (NISMF), Waipio. Minor berthing areas include ALFA Docks (Bishop Point) near the Pearl Harbor entrance channel, and VICTOR Pier 2/6 on the Pearl City Peninsula along the northeast portion of East Loch. Additionally, the U.S. Army has a facility on the northern shore of Ford Island for vehicle transport vessels.

Naval Station Pearl Harbor (NAVSTA), located along the western shore of Southeast Loch, is homeport to 11 surface ships and approximately 68 service craft (NAVSHIPSO, 1998; U.S. Navy, 1998). The NAVSTA Port Operations Department provided SSC San Diego with an accurate in-water service craft count.

Although not factored into these loading calculations, Pearl Harbor is subject to numerous port visits by non-homeported vessels. United States and foreign naval vessels frequently berth for short time periods following major exercises, such as Rim of the Pacific (RIMPAC), before and after over-sea deployments, and as part of official port visits. These in-port times vary depending on operational and scheduling requirements. An added complexity in quantifying vessel discharge from temporary visitors is the periodicity of local exercises that may occur annually or biannually. Most visiting naval vessels temporarily berth at various NAVSTA piers for an undetermined period of time.

NAVSTA Vessel dissolved copper loading:

Pierside and In-transit		
Hull Leachate:	1,874	kg/yr
Seawater Cooling:	267	kg/yr
Firemain Discharge:	46	kg/yr
Non-oily Waste Discharge:	N/A	
(data for aircraft carriers only)		
In-transit only		
Graywater Discharge:	trace	kg/yr
Total:	2,187	

There are currently 22 submarines assigned to SUBASE Pearl.

SUBASE Pearl Vessel dissolved copper load:

Pierside and In-transit		
Hull Leachate:	2,122	kg/yr
Seawater Cooling:	1,096	kg/yr
Firemain Discharge:	94	kg/yr
Non-oily Waste Discharge:	N/A	
(data for aircraft carriers only)		
Total:	3,312	

The Naval Inactive Ship Maintenance Facility (NISMF), in upper Middle Loch along the East Side of Waipio Peninsula, is responsible for the long- and short-term storage of inactive and decommissioned naval vessels. There are 70 vessels (37 ship and 43 service craft) assigned to NISMF as detailed by the NISMF Operations Manager. NISMF provided an updated list of vessels and service craft current as of 01 February 1998. Conversations with the NISMF Project Manager confirmed the locations of the vessels and also confirmed that no shipboard systems on inactive vessels are in operation.

Hull cleaning is not performed on inactive and decommissioned vessels so this source is not factored into the copper loading from NISMF.

NISMF Vessel dissolved copper load:

Pierside		
Hull Leachate:	404	kg/yr

ALFA Docks (Bishop Point), located on the eastern side the entrance channel to Pearl Harbor, are home to Navy salvage ships and associated support barges. Two salvage ships and a salvage barge berth at Alfa Docks as of June 1998.

ALFA Docks (Bishop Point) Vessel dissolved copper loading:

Pierside and In-transit		
Hull Leachate:	171	kg/yr/
Seawater Cooling:	51	kg/yr
Firemain Discharge:	4	kg/yr
Non-oily Waste Discharge: (data for aircraft carriers only)	N/A	
In-transit only		
Graywater Discharge:	trace	kg/yr
Total:	226	

Victor Pier 5/6 is a newly dedicated berthing area for Towed Array Surface Ships (T-AGOS) in the northern part of East Loch along the East Side of Pearl City Peninsula. One MSC vessel moors at Victor Pier 5/6 with more likely to be assigned in the future.

VICTOR Pier Vessel dissolved copper loading:

Pierside and In-transit		
Hull Leachate:	25	kg/yr
Seawater Cooling:	13	kg/yr
Firemain Discharge:	2	kg/yr
Non-oily Waste Discharge: (data for aircraft carriers only)	N/A	
In-transit only		
Graywater Discharge:	Trace	kg/yr
Total:	40	

The U.S. Army keeps two medium landing ships in Pearl Harbor berthed along the northern shore of Ford Island. Hull leachate is the only copper source from these vessels.

Pierside		
Hull Leachate:	61	kg/yr

Navy Hull Cleaning

Analysis of the NAVSEA hull cleaning database documented the following annual complete hull cleanings in Pearl Harbor from 1991 to 1997:

Year	# full hull cleanings*
1991	13
1992	16
1993	11
1994	10
1995	11
1996	26
1997	41
7-year average:	18

Only the 1997 cleaning data were used to identify the actual Navy ships cleaned for hull cleaning load calculation. The hull cleaning formula was then applied to the wetted hull area specific to that vessel class. There were 41 hull cleanings in the Pearl Harbor area during 1997.

U.S. Navy hull cleaning dissolved copper load:

Hull Cleaning:	33	kg/year

Civilian Pleasure Craft and Small Boats

During the February 1998 site visit to Pearl Harbor, SSC San Diego scientists visited the three main pleasure craft facilities within the harbor. Table 9 shows boat counts and average length.

Located just south of Alfa Docks is a small pier containing six rental pleasure craft owned by the MWR Department of Hickam Air Force Base. The quay wall area is less a marina than a mooring area for the boats. Again, typical assumptions place residence time as 365 days within Pearl Harbor, when actual boat usage may well result in less time in harbor vice at sea. During the recent site visit, thus more accurate transit information was not available.

The former USS *Missouri* (BB-63) was permanently moored along the south side of Ford Island in May 1998. Although berthed on Navy property, the vessel is owned and operated by a non-profit civilian agency. Because of the age of the anti-fouling paint, a conservative leachate rate of 1.0 $\mu g/cm^2/day$ was assumed.

Table 9. Marinas queried in Pearl Harbor, HI, regarding pleasure boat counts.

Sub-Region	Marina name	# of boats	Total # of slips	Avg. length (m)
Entrance Channel	Iroquois Point Marina	53	unk	10.7
Entrance Channel	MWR Rental Berthing	6	10	10.7
East Loch- Aiea Bay	Rainbow Marina	75	unk	10.7
	Total	134		

Civilian Pleasure Craft dissolved copper load:

Anti-fouling Paint Hull Leachate: *	224	kg/yr
Hull cleaning operations:	80	kg/yr
Total:	304	

* includes hull leachate from Ex-*Missouri* (BB-63) of 38 kg/yr

Direct Shore Discharges

The Pearl Harbor Naval Shipyard (PHNSY) represents the major shore-based direct discharger to the harbor. Most of PHNSY maintenance facilities and dry-docks are located along the southern edge of the South Channel adjacent to NAVSTA and across from Ford Island (figure 12).

There are four dry-docks and six outfalls at PHNSY. Dry-dock #4 with two outfalls discharges only to the Main Channel while the remaining outfalls discharge to the South Channel. For this study, the decision was made to group the outfall data by the region affected. Discharge Monitoring Reports for total copper from PHNSY were reviewed for 1-year periods for the South Channel region (Outfalls 001, 002A, 002B, May 1996 through May 1997) and Main Channel region (Outfalls 004A and 004B, July 1995 through July 1996). There were no data available for Outfall 003. A geometric mean con-

centration was taken of each composite (18.7 and 20.3 µg/L total copper, respectively). The high reporting detection limit for PHNSY copper analysis that appeared to be 25 µg/L remains a point of concern. One-half the detection limit was substituted as the concentration for geometric mean determination in those cases where values were below detection limits. Additionally, a single excessive total copper concentration of 3,800 µg/L was not used in the geometric mean calculations (Outfall 001 on November 1996). This excessively high value appears to have been a one-time anomaly and was not indicative of normal shipyard discharges. The resulting total copper value was adjusted to dissolved copper based on the U.S. EPA total-to-dissolved copper ratio of 0.83 (United States Environmental Protection Agency, 1995).

Daily flow data were only available for all shipyard dry-docks combined at 6.1 MGD (2.2×10^7 L/day), so an assumption that two-thirds went to the South Channel and one-third to the Main Channel was applied. However, given the cyclic operational tempo for these dry-docks, another unsubstantiated assumption was applied where it was assumed that this daily flow occurs 365 days/year.

The Fort Kamehameha Sewage Treatment Plant (STP) located on the East Side of the Entrance Channel services naval commands and naval housing areas within Pearl Harbor, as well as the adjacent Hickam Air Force Base. Fort Kamehameha represents the only other known DoD direct discharger, with the main outfall on the channel bottom west of the plant. Of note is the planned relocation of this outlet to deeper water outside of the Entrance. Based on the discharge depths and prevailing along shore currents, this would effectively remove the influence of the discharge plume upon Pearl Harbor. PACDIV reports that construction is slated to begin in July 1999 and estimated to take approximately 18 months. An average total copper discharge concentration of 20 µg/L was reported in a letter from the USEPA based on a review of NPDES required Discharge Monitoring Reports from 1991 to 1996 (United States Environmental Protection Agency, 1996a). Permitted flow is 13 MGD (4.9×10^7 L/day). The resultant total copper discharge was adjusted to dissolved copper with the EPA 0.83 total-to-dissolved ratio.

A copper loading source not factored into the total harbor load is the cooling water flow from the Waipio power-generating facility located along the northern shore of East Loch. Operated by the Hawaiian Power Company, this facility outputs a high-volume cooling water discharge into East Loch. Conversations with company officials revealed that the inlet and outlet pipes are composed of titanium vice copper piping, which would reduce copper pipe leachate. Continuous boiler blowdowns of the steam boilers are a regular maintenance procedure, however, and this may result in additional copper leachate. Copper concentration in the discharge stream is, therefore, unknown at present and not quantified for this study.

Direct shore-based discharge copper load:

Navy Permitted Discharges:	437	kg/yr
Civilian Permitted Discharges:	unk	
Total:	437	

Civilian Commercial Ship Traffic

Although Pearl Harbor is Navy-controlled and not subject to commercial ship traffic, there are regularly scheduled tour boat services to the harbor. Pacific Division, Naval Facilities Engineering Command (1990) identified approximately nine tour boats that routinely visit Pearl Harbor and pro-

vided their estimated hull length. An average wetted hull area for these vessels was used along with an estimated residence time of 2 hours and the NAVSEA-derived hull leachate value to determine a dissolved copper load.

Civilian Transit: 9 kg/yr

Stormwater

The Pearl Harbor watershed drains an area of approximately 291 km^2 (112 mi^2), and is composed of seven sub-watersheds (figures 16 and 17) (Pacific Division, Naval Facilities Engineering Command, 1990; Grovhoug, 1992). Runoff and sheet flow associated with the piers and surface areas of the NAVSTA/SUBASE/PHNSY was termed an "eighth" watershed by SSC San Diego for this report.

Land use. Land use data for Pearl Harbor are currently unavailable from the USEPA Basins data sets. To estimate the stormwater copper load, SSC San Diego applied a land use classification to the various sub-watersheds by overlying a grid and assigning the appropriate land use classification to each grid. Topographic maps, nautical charts, and aerial photographs were reviewed to determine a grid's specific classification. In addition, SSC San Diego staff provided input as to recent urbanization trends in Hawaii. Since the approximate areas of each sub-watershed were known, the percentage of a particular classification grid relative to the total number of grids in that watershed permitted an approximate area for that classification to be determined (figure 18, table 10).

Table 10. Land use for Pearl Harbor sub-watersheds as determined by site assessment.

Land Use Category	Waikele Area (km^2 / acres)	Waikele % of total	Waiawa Area (km^2 / acres)	Waiawa % of total	Waimalu Area (km^2 / acres)	Waimalu % of total	Honouliuli Area (km^2 / acres)	Honouliuli % of total	Halawa Area (km^2 / acres)	Halawa % of total	Aiea Area (km^2 / acres)	Aiea % of total	Ewa Area (km^2 / acres)	Ewa % of total	DoD Area (km^2 / acres)	DoD % of total
Residential	20.3 / 5,071	21 %	13.1 / 3,230	21 %	13.5 / 3,336	30 %	6.0 / 1,477	15 %	2.9 / 712	21 %	7.8 / 1,920	60 %	6.6 / 1,629	64 %	1.6 / 394	29 %
Commercial	0	0	1.6 / 404	3 %	4.7 / 1,168	11 %	0	0	1.4 / 339	9 %	1.3 / 320	10 %	0.7 / 175	7 %	2.3 / 563	29 %
Industrial	1.4 / 346	1 %	4.9 / 1,211	8 %	1.4 / 334	3 %	0	0	0	0	0	0	0.5 / 116	5 %	3.4 / 844	44 %
Roads	1.9 / 461	2 %	1.6 / 404	3 %	1.4 / 334	3 %	13.9 / 3,446	3 %	0.9 / 226	6 %	1.3 / 320	10 %	0.2 / 58	2 %	0.5/ 113	6 %
Agriculture	33.1 / 8,184	34 %	8.7 / 2,153	14%	0	0	17.9 / 4,431	46 %	0	0	0	0	1.4 / 349	14 %	0	0
Open / Parks	41.5 / 10,258	42 %	33.8 / 8,343	53 %	23.6 / 5,838	53 %	13.9 / 3,446	36 %	10.1 / 2,485	65 %	2.6 / 640	20 %	0.9 / 233	9 %	0	0
Total	98.0 / 24,230		63.7 / 15,744		44.5 / 11,008		38.8 / 9,600		15.5 / 3,840		12.9 / 3,200		10.4 / 2,560		7.7 / 1,913	

Pearl Harbor Sub-watershed: Waikele, Waiawa, Waimalu, Honouliuli, Halawa, Aiea, Ewa, DoD.

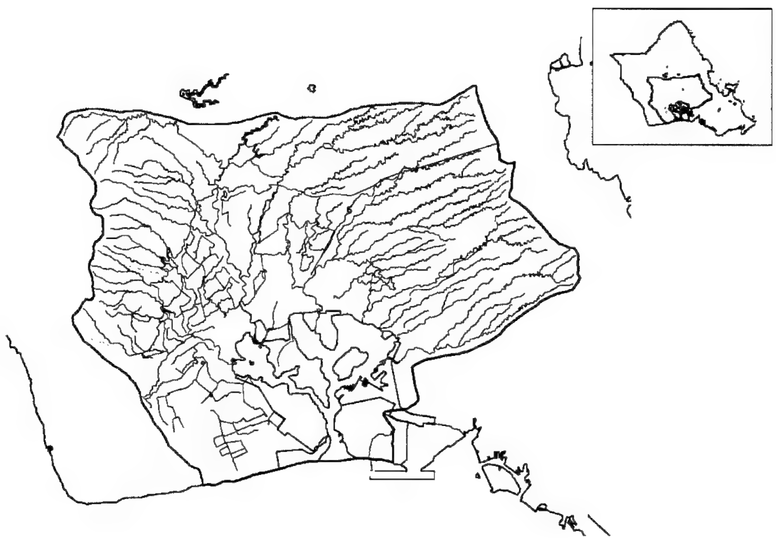


Figure 16. Pearl Harbor watershed and relative proportion to Oahu land area.

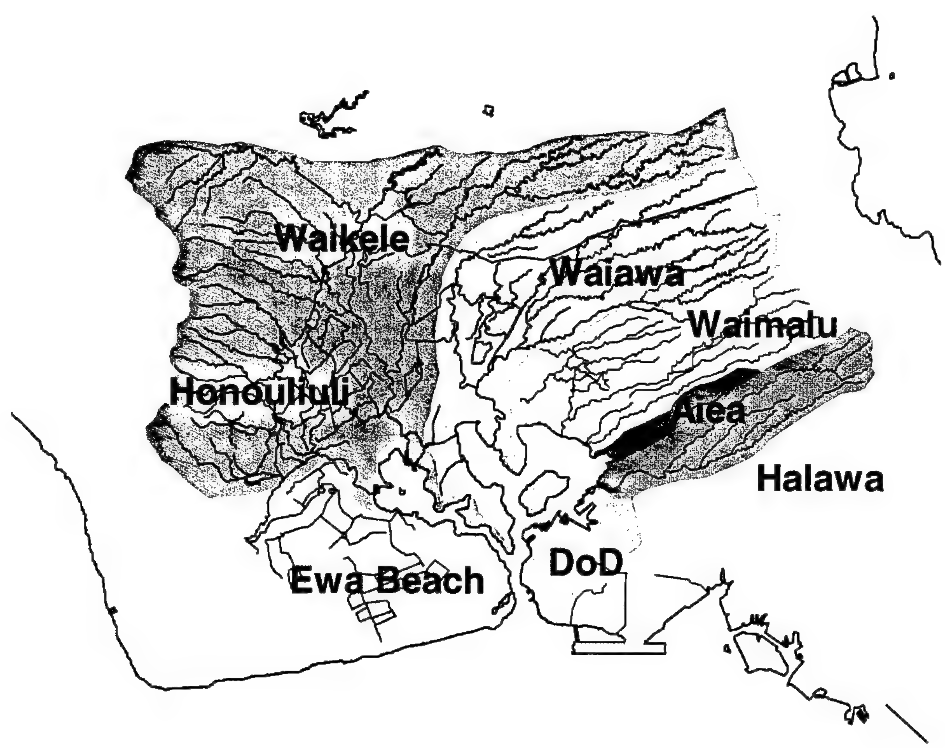


Figure 17. Pearl Harbor sub-watersheds.

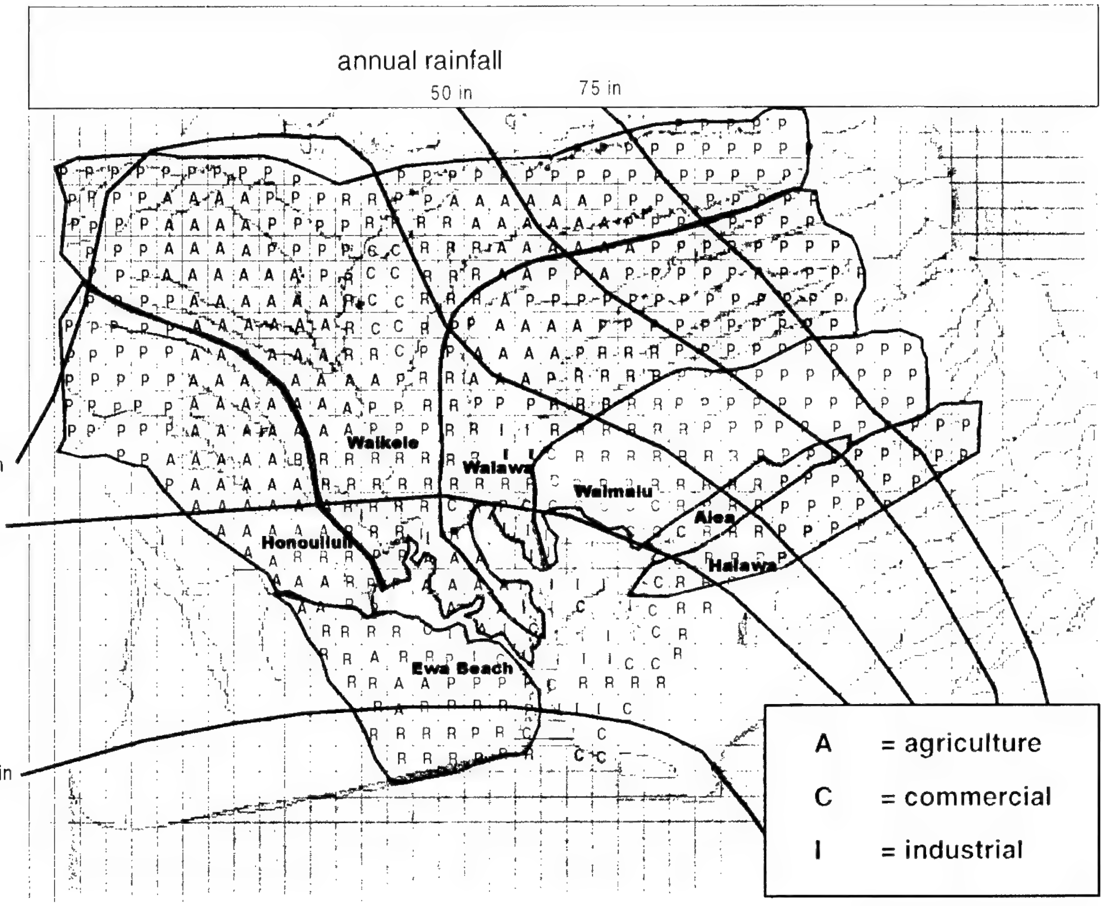


Figure 18. Land use grid for Pearl Harbor.

The immediate areas surrounding the harbor have been subject to residential and commercial development for the past 50 years. Many former agricultural areas are also being converted to residential housing along the perimeter of West Loch. The steep mountain ridges above Pearl Harbor remain as relatively undeveloped rainforest, and can be a significant portion of some sub-watershed land use. The three largest sub-watersheds, Waikele, Waiawa, and Waimalu, are all close to 50% rainforest.

Annual Rainfall. Annual rainfall for Oahu can vary from 50.8 cm/yr (20 in/yr) to over 190.5 cm/yr (75 in/yr) in the surrounding Koolau and Waianae Mountains, which drain toward the harbor (Grovhoug, 1992). Estimated annual rainfall was determined for each sub-watershed based on relative proximity to the harbor or mountains.

Sub-watershed	Annual Rainfall (in/yr)
Halawa	40.0
Aiea	35.0
Waiawa	40.5
Waimalu	40.5
Waikele	30.0
Honouliuli	30.0
Ewa	20.0
DoD	25.0

Event Mean Concentrations (EMC). There is little stormwater or water quality monitoring data available for Pearl Harbor. Therefore, region-specific EMCs were not available. As a substitute, SSC San Diego used the verified EMCs derived for San Diego (Woodward-Clyde International America, 1997). This introduces a greater degree of uncertainty to the stormwater copper loading estimates. However, it does provide, at a minimum, a conservative means to quantify stormwater loading (table 14). Unlike Norfolk, the San Diego EMCs do not provide a value for "forest" land use. The rainforest land areas were, therefore, added to the parks/open classification.

Perviousness. The San Diego impervious values were used as mentioned above because of a lack of region specific values (table 15).

Stormwater and baseflow runoff dissolved copper load:

Pearl Harbor Sub-watershed Stormwater:	730	kg/yr
Sub-watershed Baseflow:	108	kg/yr
Total:	838	

Atmospheric Deposition

Kennish (1997) presents an atmosphere-to-surface deposition rate of 0.0089 $\mu g/cm^2/yr$ for the North Pacific. Given the small water surface area of Pearl Harbor (21 km^2), copper loading from atmospheric deposition would be expected to be low:

Atmospheric deposition copper load:

Atmospheric Deposition:	2	kg/yr

Other Sources

Pearl Harbor has numerous natural springs and a shallow aquifer that generates a significant fresh-water flow into Pearl Harbor. However, lack of copper concentration and quantifiable flow rates precludes including groundwater transport as a loading term.

SAN DIEGO, CA

San Diego Bay, located along the southernmost portion of California (figure 19), is the largest Navy homeport on the West Coast. Unlike Norfolk or Pearl Harbor, this semi-arid region receives relatively little precipitation. Annual rainfall is typically less than 25.4 cm/yr (< 10 inches/yr). Fresh-water input to the enclosed bay is, therefore, fairly limited, and tidal currents are the dominant mixing force in the harbor. San Diego's increasingly heavy urbanization and industrialization has negatively impacted ambient water and sediment quality over the years.

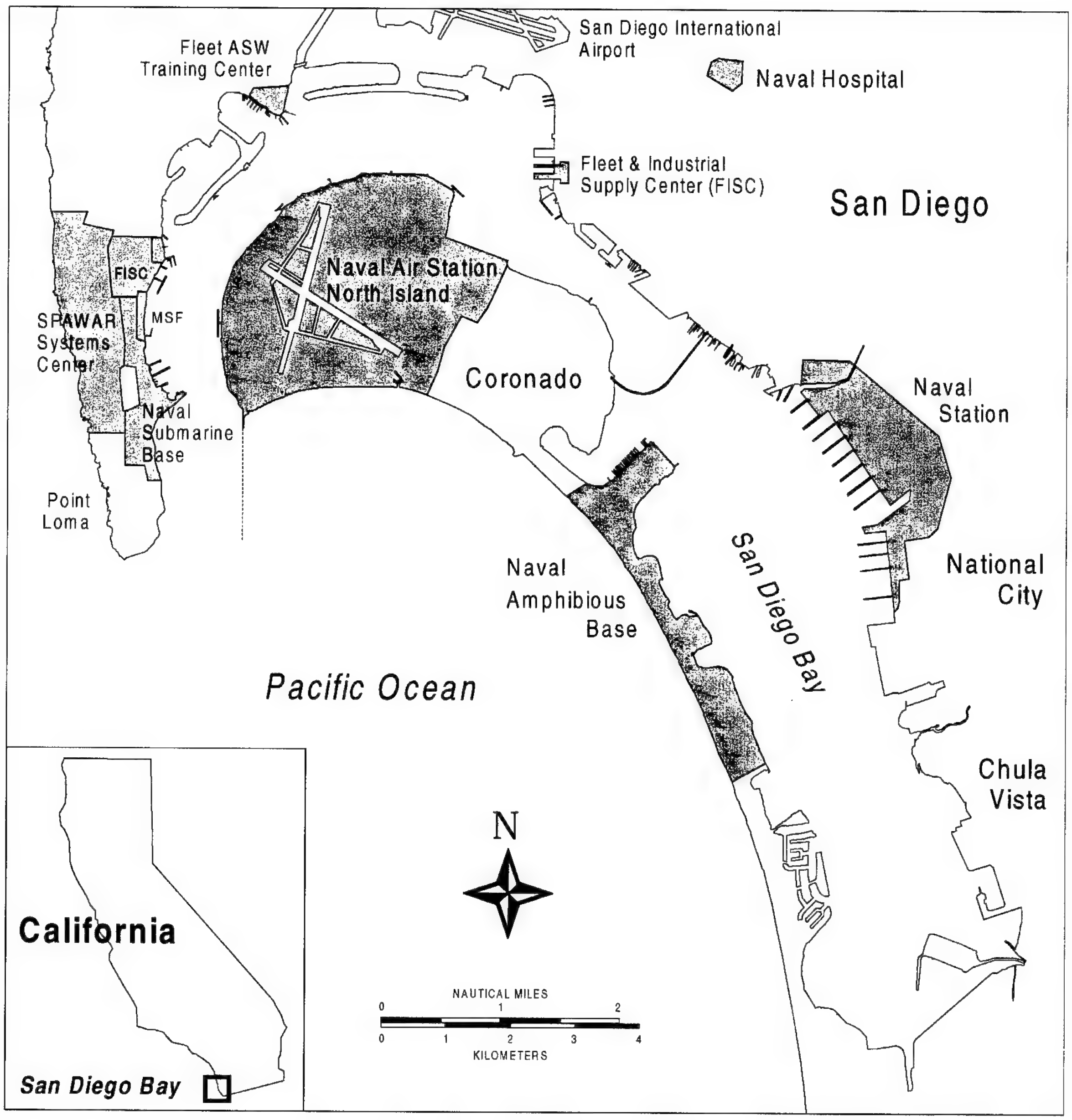


Figure 19. San Diego, CA, showing COMNAVBASE San Diego facilities.

ENVIRONMENTAL DATA SOURCES

SSC San Diego has been gathering San Diego-specific water and sediment data since the 1970s and has developed a 200,000 record database comprising data from U.S. Navy, Federal, State, and regional agency studies. Most available datasets pertinent to San Diego have been, or are, in the process of undergoing conversion for inclusion into this environmental database.

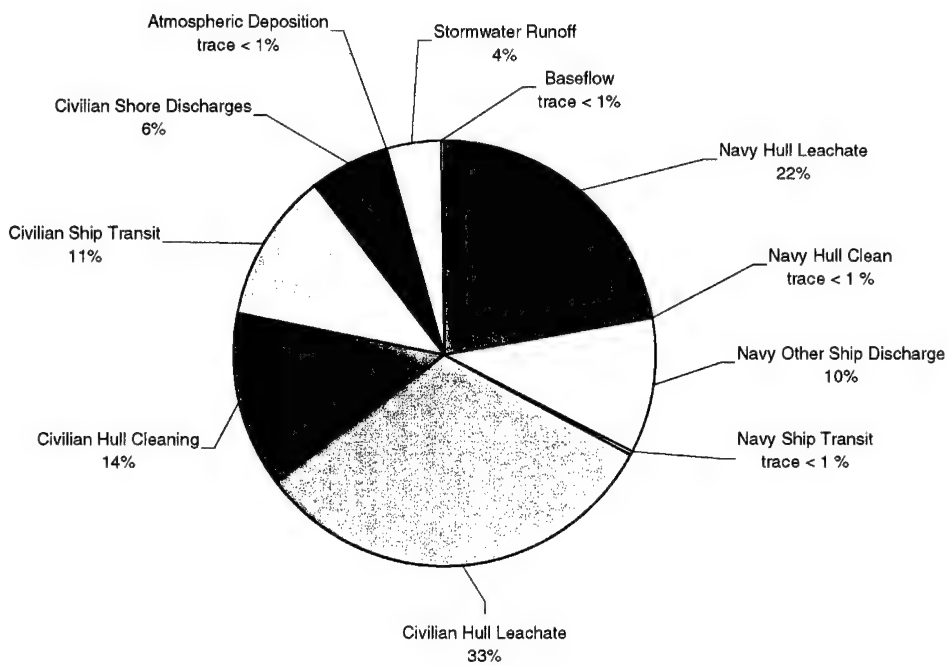
The most current San Diego Bay copper water concentration data were reported from a survey conducted in November 1997 (Katz, 1998). An increasing gradient of copper concentration progressing from the Bay mouth to the middle portion of the Bay adjacent to a region of commercial shipbuilding activity and traditional surface ship berthing areas for Naval Station San Diego was reported (figure 20).

Figure 20. Dissolved Cu (µg/L) distribution in San Diego Bay for November 1997 (modified from Katz, 1998).

SAN DIEGO COPPER LOAD

San Diego is the only harbor with a large U.S. Navy presence where copper loading was dominated by a civilian source. A combination of both Navy ship sources and civilian boat sources resulted in the highest total load (32,422 kg/year) of any harbor under review (figures ES-1 and 21).

Civilian pleasure boat hull leachate accounted for nearly 33% of the total load, followed by 22% for Navy hull leachate, and 14% for pleasure craft hull cleaning. San Diego has a large number of in-water pleasure craft within a relatively small geographic area. Over 7,400 boats have been documented in the most recent San Diego Harbor Police annual census.



Source	Annual Dissolved Copper Discharge (kg/yr)
Navy Hull Leachate	7,194
Navy Hull Cleaning	30
Navy Other Ship Discharges	3,328
Navy Ship Transit Discharges	106
Navy Shore Discharges	N/A
Civilian Small Boat Hull Leachate	10,287
Civilian Small Boat Hull Cleaning	4,402
Civilian Ship Transit/Hull Leachate	3,685
Civilian Shore Discharges	1,984
Atmospheric Deposition	7
Stormwater Runoff	1,328
Watershed Baseflow	125
Total:	32,474

Figure 21. Relative source percentage of copper loading to San Diego, CA.

SAN DIEGO SITE-SPECIFIC LOADING ASSUMPTIONS

Figures 22 and 23 show San Diego copper loading sites.

Navy Hull Leachate and Vessel Discharges

There are three major Navy facilities in San Diego. These include Submarine Base San Diego (SUBASE) located on Point Loma, Naval Air Station North Island (NASNI) located on the northern portion of the Coronado peninsula, and Naval Station San Diego (NAVSTA) located along the eastern middle portion of San Diego Bay (figures 19 and 22).

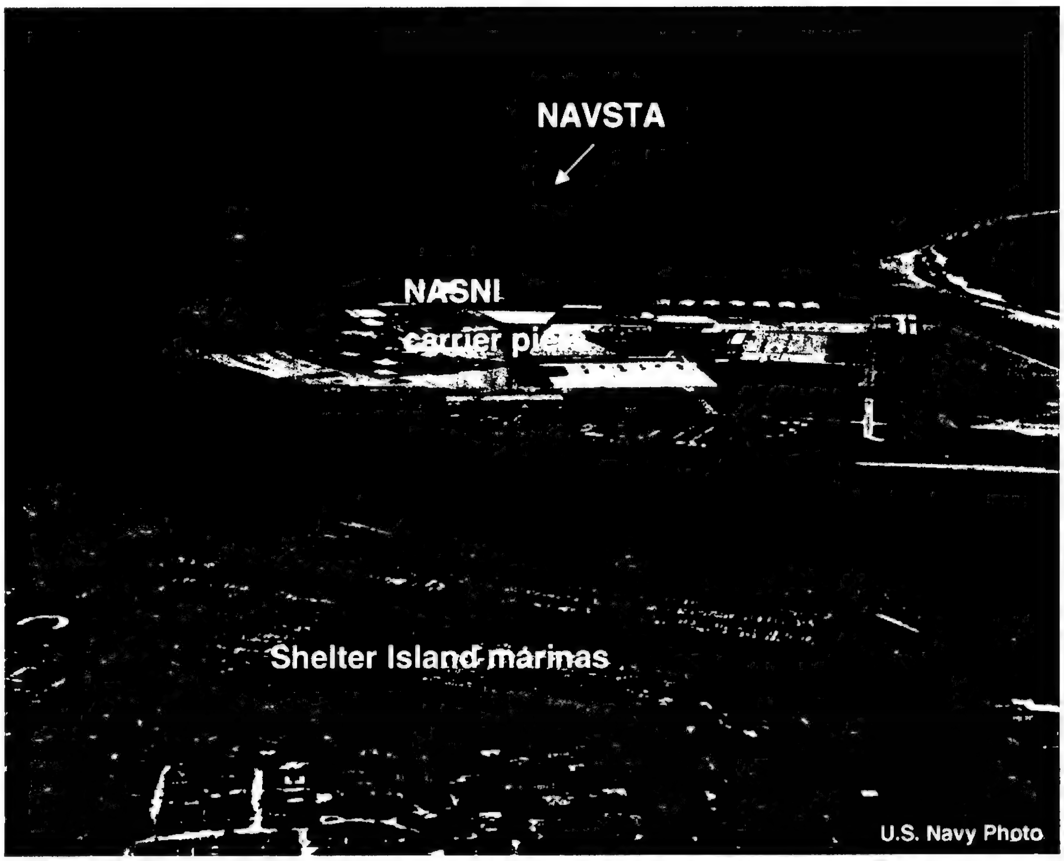


Figure 22. San Diego Bay (north-south) showing pleasure craft mooring (foreground), Naval Air Station North Island (middle), and Naval Station San Diego (background).

Submarine Base San Diego (SUBASE), the closest Navy facility to the San Diego Bay entrance, currently has seven submarines, a submarine tender, and a command-and-control surface ship assigned to this command.

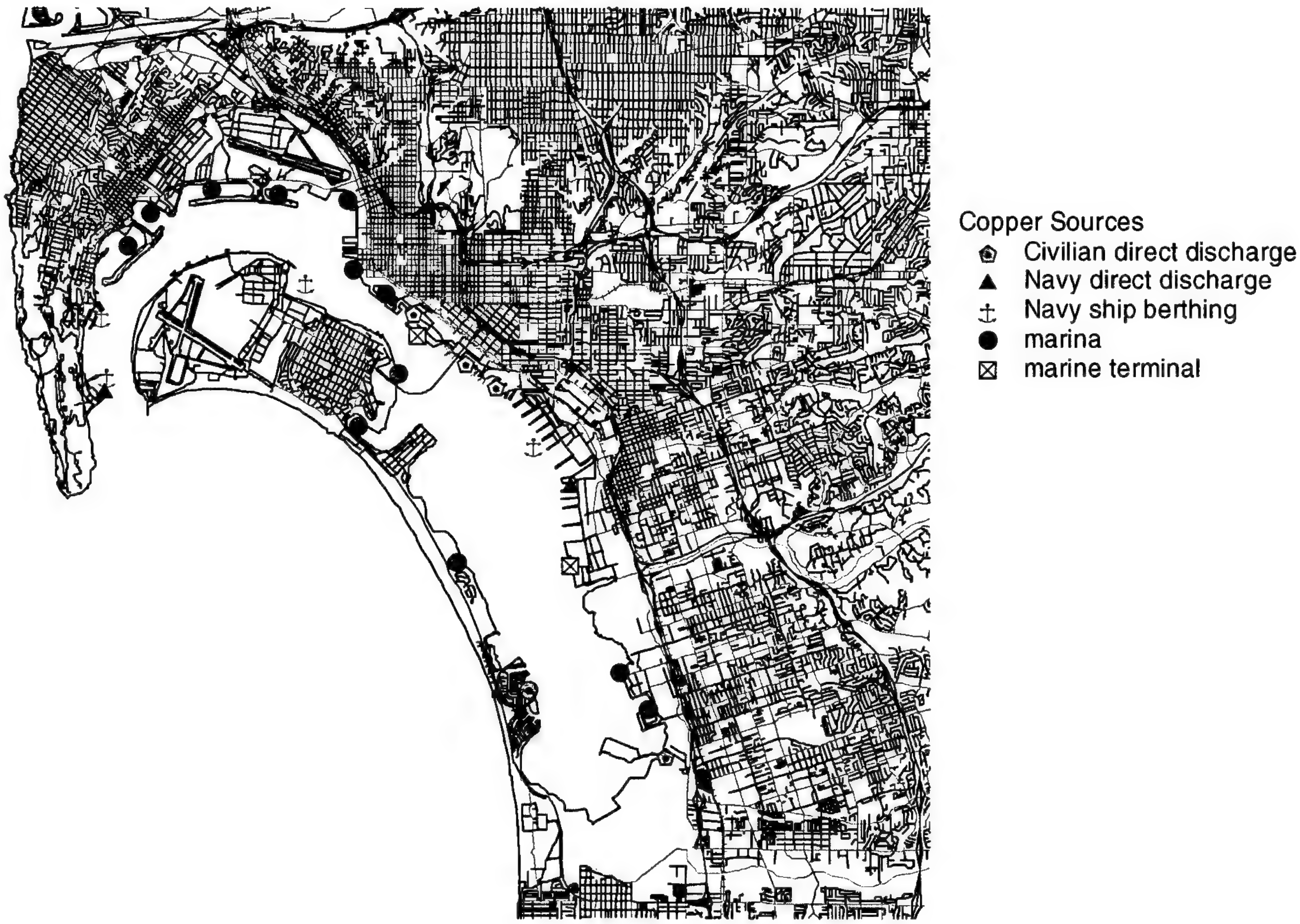


Figure 23. Potential copper release sites for San Diego, CA.

SUBASE Vessel dissolved copper load:

Pierside and In-transit		
Hull Leachate:	1,017	kg/yr
Seawater Cooling:	488	kg/yr
Firemain Discharge:	45	kg/yr
Non-oily Waste Discharge:	0	kg/yr
(data for aircraft carriers only)		
In-transit only		
Graywater Discharge:	trace	kg/yr
Total:	1,550	

Dissolved copper load by discharge category for Navy berthing sites at SUBASE:

Hull Leachate:	1,017	kg/year
Other Discharges:	525	kg/year
In-transit Discharges:	8	kg/year
Total:	1,550	

Two aircraft carriers (one CVN and one CV) moor at the carrier piers adjacent to Naval Airstation North Island (NASNI) (figure 24). Eventually, up to three CVNs are scheduled for assignment to San Diego in the next decade.

NASNI Vessel dissolved copper load.

Pierside and In-transit		
Hull Leachate:	720	kg/yr
Seawater Cooling:	477	kg/yr
Firemain Discharge:	53	kg/yr
Non-oily Waste Discharge:	35	kg/yr
(data for aircraft carriers only)		
In-transit only		
Graywater Discharge:	trace	kg/yr
Total:	1,285	

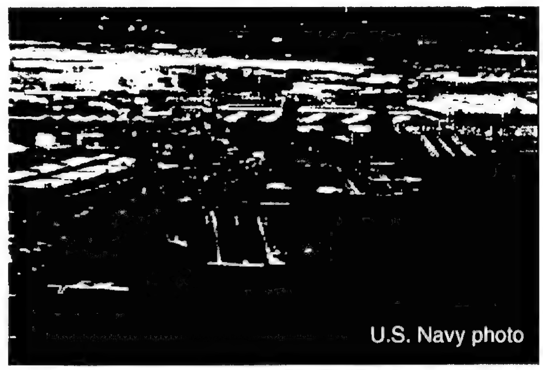


Figure 24. Aerial view of NASNI (south-to-north) showing carrier berthing.

Dissolved copper load by discharge category for Navy berthing sites at NASNI:

Hull Leachate:	720	kg/year
Other Discharges:	547	kg/year
In-transit Discharges:	18	kg/year
Total:	1,285	

Naval Station San Diego (NAVSTA) is currently home to 50 major surface ships including combatants, amphibious assault ships, naval auxiliaries, coastal warfare vessels, and the hospital ship USNS Mercy. In addition, larger hull U.S. Coast Guard vessels also use NAVSTA piers.

NAVSTA Vessel dissolved copper load:

Pierside and In-transit		
Hull Leachate:	5,322	kg/yr
Seawater Cooling:	1,960	kg/yr
Firemain Discharge:	267	kg/yr
Non-oily Waste Discharge: (data for aircraft carriers only)	N/A	
In-transit only		
Graywater Discharge:	trace	kg/yr
Total:	7,549	

Dissolved copper load by discharge category for Navy berthing sites at NAVSTA:

Hull Leachate:	5,322	kg/year
Other Discharges:	2,152	kg/year
In-transit Discharges:	75	kg/year
Total:	7,549	

Military Sealift Command has four vessels homeported in San Diego. The two tankers and two ocean tugs historically had been berthed at the Fleet Industrial Supply Center piers adjacent to downtown San Diego. Current harbor observations, however, show these vessels mooring at various other Navy locations within the harbor (SUBASE, NASNI, NAVSTA) depending on pier availability and operational commitments.

MSC Vessel dissolved copper load

Pierside and In-transit		
Hull Leachate:	135	kg/yr
Seawater Cooling:	103	kg/yr
Firemain Discharge:	6	kg/yr
Non-oily Waste Discharge: (data for aircraft carriers only)	N/A	
In-transit only		
Graywater Discharge:	trace	kg/yr
Total:	379	

Navy Hull Cleaning

Analysis of the NAVSEA hull cleaning database documented the following annual complete hull cleanings in San Diego:

Year	# full hull cleanings
1990	29
1991	47
1992	28
1993	32
1994	36
1995	46
1996	39
1997	30
8-year average:	36

There were 30 hull cleanings in San Diego based on analysis of the NAVSEA 1997 hull cleaning database.

U.S. Navy hull cleaning dissolved copper load:

Hull Cleaning: 30 kg/year

Direct Shore Discharges

There are relatively few direct industrial shore discharges to San Diego Bay. The predominate shore activities that could provide copper input to the Bay are shipyard operations and power plant cooling water flow. Based on a combination of 1996 and 1994 sediment monitoring and deposition data, PRC Environmental Management, Inc. (1997) calculated the copper loading estimates for San Diego direct dischargers as summarized in table 11.

Table 11. Copper-loading estimates for San Diego direct dischargers.

Source	Category	Annual Cu Load (kg/yr)
Southwest Marine	Shipyard	354
Continental Marine	Shipyar	72
Campbell Shipyard	Shipyard	222
NASSCO	Shipyard	718
Commercial Basin	Boat Repair	540
San Diego Gas and Electric	Power Plant	26
	Total Direct Discharge Copper Load	1,932

Civilian Pleasure Craft and Small Boats

San Diego is home to a large population of pleasure craft that dominate the total copper-loading budget based on hull leachate and hull cleaning estimates. Although wetted hull areas for this type of boat are relatively small as compared to the large hull commercial and naval vessels, with close to 7,400 boats in San Diego Bay, the impact of pleasure craft hull loading on the total copper budget is significant. The San Diego pleasure boat count was also more accurate as compared to Norfolk, for instance. The San Diego Unified Port District's Harbor Police, which have Bay-wide enforcement jurisdiction, conduct an annual pleasure craft survey within San Diego Bay. These counts do not represent only slip counts, but are confirmed occupancy counts at the various marinas and docks lining the Bay. The 1997 survey results are presented in table 12.

Table 12. 1997 San Diego Harbor Police pleasure craft survey results.

Pleasure Craft Location	# of boats	Avg. Length (m)
Shelter Island	2,242	10.7
America's Cup Harbor	723	10.7
Harbor Island – WEST	1,412	10.7
Harbor Island – EAST	559	10.7
Laural Street	157	10.7
Embarcadero	463	10.7
Coronado – Roadstead	69	10.7
Coronado – Glorietta Bay	341	10.7
Coronado – Cays	231	10.7
Coronado – Silver Strand	364	10.7
National City	170	10.7
Chula Vista	668	10.7
Total	7,399	

Civilian pleasure craft copper load:

Anti-fouling Paint Hull Leachate:	10,287	kg/yr
Hull cleaning operations:	4,402	kg/yr
Total:	14,689	

Civilian Commercial Ship Traffic

The Port of San Diego does not host a high volume of commercial ship traffic common to the Port of Norfolk on the East Coast, and the Port of Los Angeles north of San Diego on the West Coast. PRC Environmental Management, Inc. (1997) obtained detailed approximations of civilian vessel movements for San Diego from the San Diego Unified Port District. The relatively high contribution that civilian commercial ship traffic load provides to the total copper budget for San Diego, as com-

pared to the civilian ship traffic load for the higher volume port of Norfolk, can be attributed to the longer residence time assigned to the "miscellaneous and visiting" category presented in table 13. A residence time of 10 days per year was used by PRC whereas in the Norfolk copper load section, a residence time of 2 days was used for all civilian traffic.

Table 13. San Diego commercial vessel traffic based on San Diego Unified Port District information as reported by PRC Environmental Management Inc. (1997).

Vessel Type	# per year	Avg. wet hull area per vessel (m^2)	SD Bay Residence Time (days/yr)	AF paint release rate (ug/cm^2/ day)	Annual Cu Load (kg/yr)
Passenger/ Cruise	14	3,459	2	17	16
Cargo	148	9,121	3	17	688
Barges	25	334	3	17	4
Marine Construction	10	334	244	17	139
Miscellaneous and Visiting	290	4,967	10	17	2,449
Tug Boats	19	334	360	17	388

Civilian commercial ship traffic dissolved copper load:

Anti-fouling Paint Hull Leachate: 3,685 kg/yr

Stormwater

Total land area within the San Diego County watershed that specifically drains to San Diego Bay is 1,144 km^2 (282,632 acres), and is composed of three sub-watersheds (figure 25).

Land Use. The San Diego Association of Governments (SANDAG), a multi-agency advisory panel composed of local municipalities and Bay stakeholders, distributes 1995 land use data through the Internet (San Diego Association of Governments, 1998a) as Geographical Information System (GIS) data layers. Watershed delineation, county land use, and San Diego Bay land use maps were generated by SSC San Diego from these data (figures 25, 26, 27). The most recent SANDAG statistics (San Diego Association of Governments, 1998b) do not adequately distinguish between industrial and commercial land use categories (table 13). For the stormwater runoff model, industrial and commercial land uses were combined into a single land use classification. The higher industrial EMC and higher commercial percent impervious values were applied to this combined classification in the model to generate a more conservative result.

Table 14. Land use categories for San Diego sub-watersheds and the associated composite category used for modeling (source: San Diego Association of Governments, 1998b).

		San Diego Bay Sub-watershed								
		Sweetwater			Otay			Pueblo San Diego		
Land Use Category Used	Original SANDAG Land Use Classification	Area (km^2)	Area (acres)	Total (%)	Area (km^2)	Area (acres)	Percent of total	Area (km^2)	Area (acres)	Percent of total
Residential	Residential	190.8	27,135	18	33.8	8,355	8%	60.0	14,825	41%
Industrial	Commercial / Industrial	13.7	3,397		26.3	6,494		25.7	6,344	
	Schools	5.5	1,357		2.0	503		4.4	1,082	
	Commercial Recreation	7.0	1,742	4	2.9	717	8%	1.5	367	22%
Agriculture	Agriculture	24.6	6,073	4	29.5	9,762	10%	0.1	15	< 1%
Open / Parks	Vacant /Undeveloped	297.4	73,498		265.3	65,553		8.6	2,115	
	Parks /Open	105.2	26,006	67	14.8	3,660	70%	8.4	2,072	12%
Roads	Freeways/Road Row	35.7	8,830	6	14.2	3,509	4%	37.4	9,241	26%
	Total:	599.1	148,038		398.8	98,553		145.9	36,061	

Annual rainfall. The long-term (1850-1992) annual rainfall as reported by PRC Environmental Management, Inc. (1997) at San Diego's Lindbergh Field Airport is 25.4 cm/year (10 in/year).

Event Mean Concentrations (EMC). Woodward-Clyde International-America (1997) have been monitoring stormwater parameters as part of an ongoing 4-year stormwater program for the City of San Diego, the San Diego Unified Port District, San Diego County, and 17 other San Diego area cities. Event Mean Concentrations presented in table 15 were the flow-weighted copper concentrations by land use classification from this 4-year period.

Table 15. Event Mean Concentrations (EMCs) from San Diego stormwater monitoring (1992-1994) as reported by Woodward-Clyde International-America (1997).

	Copper Concentration, Total (mg/L)					
City	Residential	Commercial	Industrial	Agricultural	Open	Roads *
San Diego	0.01000	0.01280	0.02400	0.01000	0.01000	0.0428

*Road EMC taken from Federal Highway Administration (1990)

Perviousness. The percent imperviousness values as reported by Woodward-Clyde International-America (table 16) were also used in the stormwater runoff model.

Table 16. Percent impervious by land use categories for San Diego (Woodward-Clyde International-America, 1997).

	% Impervious by Land use					
City	Residential	Commercial	Industrial	Agricultural	Open	Roads
San Diego	13.9	90.0	73.7	0.5	0.5	90.0

The final loading results of the Simple Method stormwater and baseflow runoff are presented below.

San Diego Stormwater Runoff dissolved copper load:

San Diego Sub-watershed Stormwater:	1,328	kg/yr
Sub-watershed Baseflow:	125	kg/yr
Total:	1,453	

Atmospheric Deposition

San Diego Bay-wide copper deposition was calculated as part of a sediment characterization study for NAVSTA, San Diego‡‡. Lacking significant sources of metal air emissions, estimated atmospheric deposition of copper to the Bay was small.

Atmospheric deposition dissolved copper load:

Atmospheric Deposition:	7	kg/yr

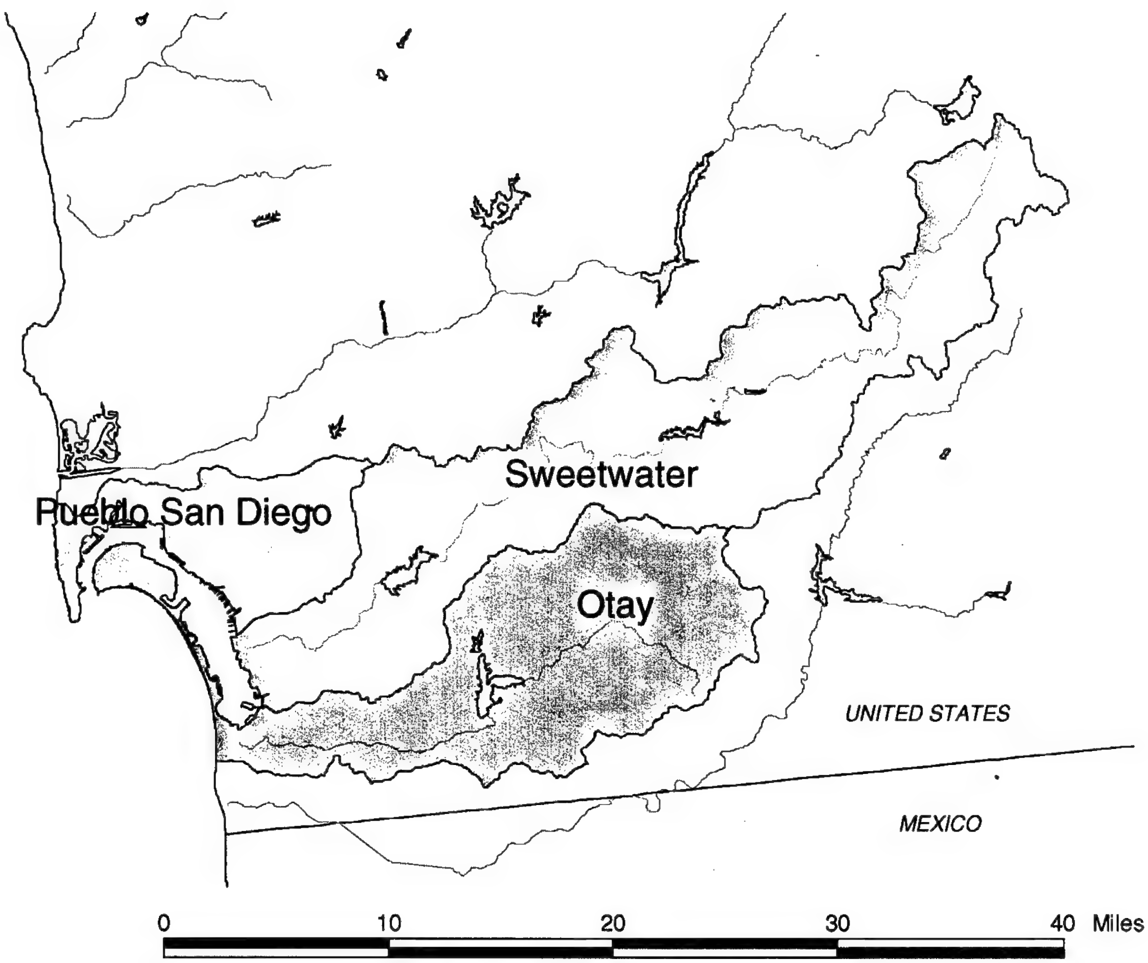


Figure 25. San Diego County sub-watersheds draining to San Diego Bay.

---

‡‡ Naval Command, Control and Ocean Surveillance Center, RDT&E Division (now SSC San Diego). 1996. Draft

Sediment Quality Characterization—Naval Station San Diego. San Diego, CA. Unpublished monitoring data.

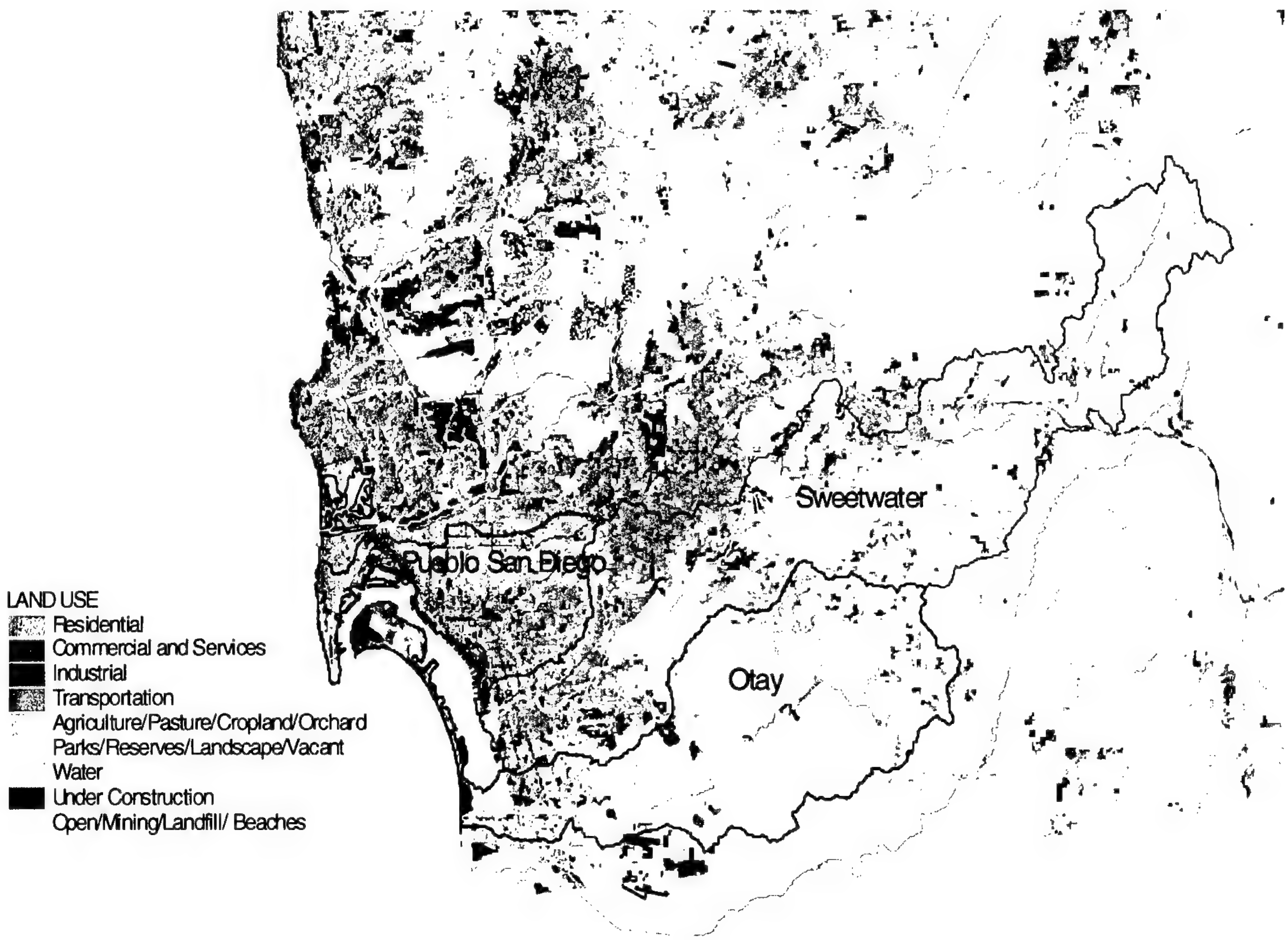


Figure 26. San Diego sub-watershed 1995 land use (source: San Diego Association of Governments, 1998).

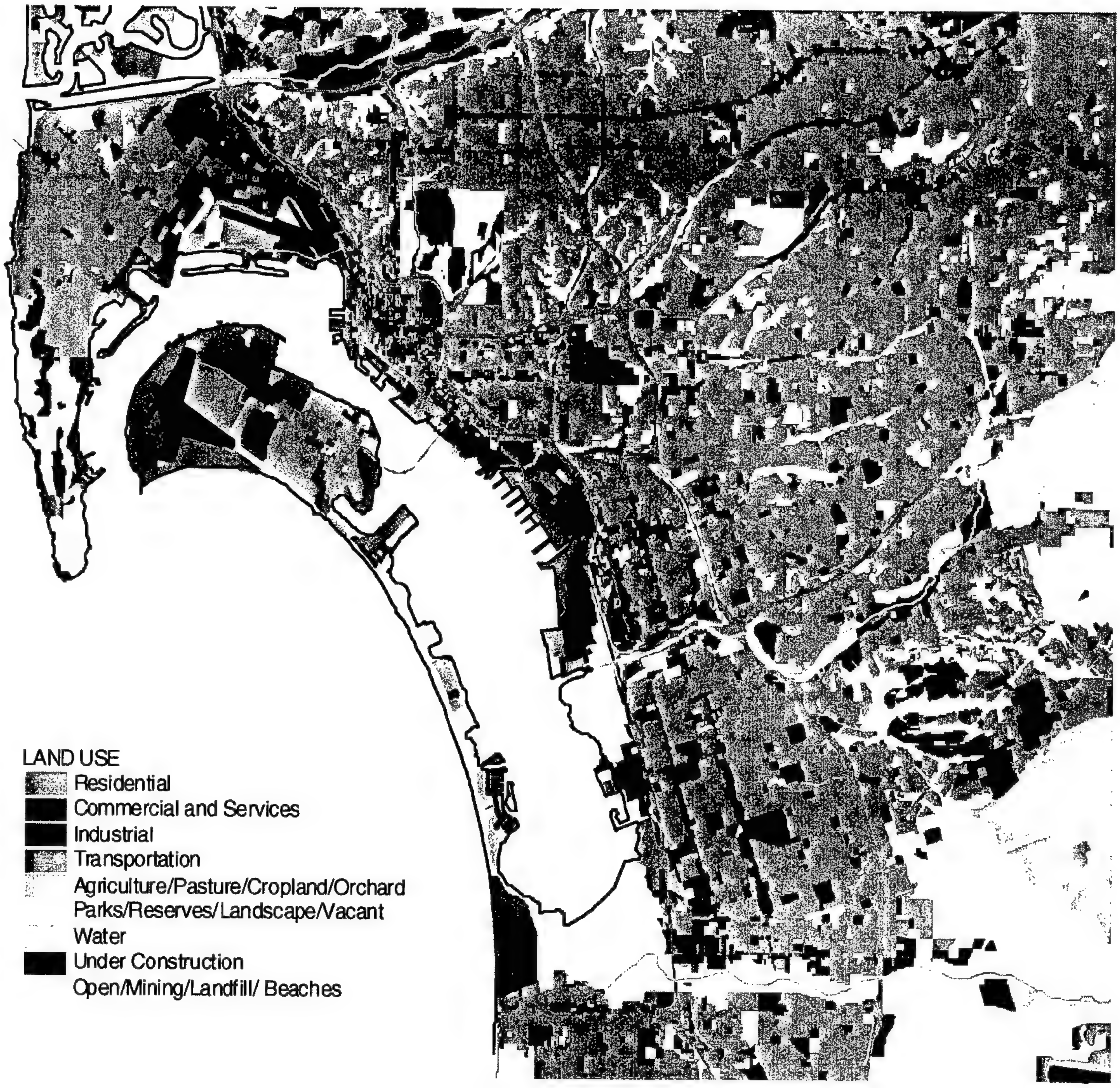


Figure 27. 1995 land use patterns adjacent to San Diego Bay (source: San Diego Association of Governments, 1998).

REFERENCES

Commission for Environmental Cooperation. 1997. *Continental Pollutant Pathways*. Montreal, Canada.

CH2M Hill, Inc. Unpublished. An Integrated Approach to Obtaining Optimal Discharge Permits. Prepared for: Atlantic Division, Naval Facilities Engineering Command, Norfolk, VA. Detroit, MI.

Chadwick, D. B., S.H. Lieberman, C. E. Reimers and D. Young. 1993. "An Evaluation of Contaminant Flux Rates From Sediments of Sinclair Inlet, WA, Using a Benthic Flux Sampling Device." NRaD TD 2434, Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Chesapeake Bay Program. 1991. "Chesapeake Bay Toxics of Concern List: Basinwide Toxics Reduction Strategy Commitment Report." Chesapeake Bay Program Toxics Subcommittee Joint Criteria and Standards Workgroup, Annapolis, Maryland.

Chesapeake Bay Program. 1994. "Chesapeake Bay Basinwide Toxics Reduction Strategy Reevaluation Report." Toxic Subcommittee, Annapolis, Maryland.

Federal Highway Administration. 1990. "Pollutant Loading and Impacts from Highway Stormwater Runoff, Vol. 3; Analytical Investigation and Research Report." FHWA-RD-88-008, McClean, VA.

Grovhoug, J. G., P. F. Seligman, R. L. Fransham, S. Y. Cola, M. O. Stallard, P. M. Stang, and A. O. Valkirs. 1989. "Butyltin Concentration Measurements in Pearl Harbor, Hawaii." TR 1293. Naval Ocean Systems Center, San Diego, CA.

Grovhoug, J. G. 1992. "Evaluation of Sediment Contamination in Pearl Harbor." TR1502. Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Katz, C. N. 1998. "Seawater Polynuclear Aromatic Hydrocarbons and Copper in San Diego Bay." TR 1768. Space and Naval Warfare Systems Center, San Diego, CA.

Kennish, M. 1997. *Practical Handbook of Estuarine and Marine Pollution.* CRC Press, New York, NY.

Atlantic Division, Naval Facilities Engineering Command. 1993. Unpublished. Ambient Copper Water Concentrations for Eight Stations. Norfolk, VA.

McPherson, T. N. and G. B. Peters. 1995. "The Effects of Copper-based Antifouling Paints on Water Quality in Recreational Bat Marina in San Diego and Mission Bay." Prepared for: California Regional Water Quality Control Board, San Diego Region. Unpublished manuscript.

Naval Amphibious Base Little Creek. 1998. Internet site:

http://www.cmar.navy.mil/NABLC/index.htm.

Naval Sea Systems Command. 1996. Chapter 633 – Cathodic Protection Table 633-5. Estimates of Wetted Surface Areas for U.S. Navy Vessels. Naval Ships' Technical Manual, October 1996. S9086-VF-STM-010. Naval Sea Systems Command, Arlington, VA.

Naval Sea Systems Command. 1997a. Nature of Discharge Report: Hull Coating Leachate. 05 Nov 1997. Naval Sea Systems Command (00T), Arlington, VA.

Naval Sea Systems Command. 1997b. Nature of Discharge Report: Underwater Ship Husbandry. 24 Nov 1997. Naval Sea Systems Command (00T), Arlington, VA.

Naval Sea Systems Command. 1997c. Nature of Discharge Report: Seawater Cooling Overboard Discharge. 22 Dec 1997. Naval Sea Systems Command (00T), Arlington, VA.

Naval Sea Systems Command. 1997d. Nature of Discharge Report: Firemain Systems. 19 Nov 1997. Naval Sea Systems Command (00T), Arlington, VA.

Naval Sea Systems Command. 1997e. Nature of Discharge Report: Non-Oily Machinery Wastewater. 19 Nov 1997. Naval Sea Systems Command (00T), Arlington, VA.

Naval Sea Systems Command Shipbuilding Support Office. 1998. Naval Vessel Register. Internet site only. http:\\www.nvr.navy.mil, Philadelphia, PA.

Naval Command Control and Ocean Surveillance Center, RDT&E Division. 1996. Draft Sediment Quality Characterization - Naval Station San Diego. (Unpublished monitoring data). San Diego, CA.

Ogden Environmental and Energy Services Company, Inc. 1996. "Final Report: Remedial Investigation/Feasibility Study (RI/FS) Work Plan for Pearl Harbor Sediment Study, Pearl Harbor, Hawaii." Prepared for: Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, HI. Honolulu, HI.

Pacific Division, Naval Facilities Engineering Command. 1990. "Final Environmental Impact Statement for Proposed Developments at Naval Base Pearl Harbor, Oahu, Hawaii." Pearl Harbor, HI.

PRC Environmental Management, Inc. 1997. Report of Copper Loading to San Diego Bay, California. Prepared for: California Regional Water Quality Control Board, San Diego Region. San Diego, CA.

San Diego Association of Governments. 1998a. Internet site: http://www.sandag.cog.ca.us

San Diego Association of Governments. 1998b. "Watersheds of the San Diego Region," *SANDAG INFO* (Mar-Apr), San Diego, CA.

Sansalone, J. J. and S. G. Buchberger. 1997. Partitioning and First Flush of Metals in Urban Roadway Storm Water. *Journal of Environmental Engineering* (Feb), pp. 134–143.

Schueler, T. R. 1987. "Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs." Pp. 275, Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, D.C.

Space and Naval Warfare Systems Center. 1998. "Chemistry, Toxicity and Bioavailability of Copper and Its Relationship to Regulation in the Marine Environment—Office of Naval Research Workshop Report." TD 3034. P. F. Seligman and A. Zirino, eds., San Diego, CA.

Shen, J., J. D. Boon, and G. M. Sisson. 1997. "Hydrodynamic Model HEM-3D: Clam Larval Dispersions, James River. Prepared for: Virginia Marine Resources Commissions," Newport News, Virginia Institute of Marine Science, Gloucester Point, VA.

URS Consultants, Inc. 1996. "Technical Assessments in Support of the Elizabeth River Regional Action Plan. Prepared for: Department of Environmental Quality," Contract No. 970500142, Virginia Department of Environmental Quality, Virginia Beach, VA.

United States Environmental Protection Agency. 1983. "Results of the Nationwide Urban Runoff Program Volume I—Final Report. Water Planning Division." Washington, DC.

United States Environmental Protection Agency. 1995. "Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliance-Revision of Metals Criteria," *Federal Register,* vol. 60, no. 86 (4 May), pp. 22229–22237.

United States Environmental Protection Agency. 1996a. "Clean Water Act Inspection of Pearl Harbor Naval Base and Hickam Air Force Base NPDES permit for Fort Kamehameha Feb 28, 1990." Letter to PWC, Pearl Harbor and Pearl Harbor Naval Base 31 May 1996.

United States Environmental Protection Agency. 1996b. Draft TMDL Program Implementation Strategy. Office of Wetlands, Oceans and Watersheds, United States Environmental Protection Agency, Washington, DC. 20 December.

United States Environmental Protection Agency. 1997. Deposition of Air Pollutants to the Great Waters: Second Report to Congress. Office of Air Quality, United States Environmental Protections Agency, Research Triangle Park, NC. EPA-453/R-97-011.

United States Environmental Protection Agency. 1998a. National Water Quality Inventory: 1996 Report to Congress. Office of Water, United States Environmental Protection Agency, Washington, DC. EPA-841-R-97-008.

United States Environmental Protection Agency. 1998b. Better Assessment Science Integrating Point and Nonpoint Sources (BASINS v 2.0). Office of Water, United States Environmental Protection Agency, Washington, DC. EPA-823-R-98-006.

United States Environmental Protection Agency. 1998c. Proposed Phase I Uniform National Discharge Standards for Vessels of the Armed Forces. Technical Development Document. Office of Water, United States Environmental Protection Agency, Washington, DC. EPA-821-R-98-009.

United States Navy. 1998. "Naval Vessels by Homeport." United States Navy Official Internet site:

http://www.navy.mil.

Virginia Department of Environmental Quality. 1997. "Virginia Ambient Water Quality Monitoring Report, Monitoring Year 1997. Water Quality Assessments," Richmond, VA. *DEQ Tech Bull.* WQA/1997-003.

Valkirs, A. O., B. M. Davidson, L. L. Kear, R. L. Fransham, A. R. Zirino, and J.G. Grovhoug. "Environmental Effects from In-water Hull Cleaning of Ablative Copper Antifouling Coatings." TD 2662. Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Virginia Port Authority. 1998. Internet Site: http://www.vaports.com

Woodward-Clyde International America. 1997. "1996-1997 City of San Diego and Co-Permittees NPDES Stormwater Monitoring Program Report." San Diego, CA.

APPENDIX A

GENERAL LOADING ASSUMPTIONS

To determine potential copper loading to any harbor, a watershed-based analysis is warranted to quantify all possible sources of a given pollutant to the marine receiving waters (United States Envirômental Protection Agency, 1996b). The most common sources of copper loading to a watershed identified include:

Navy Sources

Vessel Hull Anti-Fouling Paint Leachate

Vessel Seawater Cooling Discharge

Shore-Based NPDES Direct Discharge

Vessel Firemain Discharge

Vessel In-Water Hull Cleaning Operations

Non-Navy Sources

Vessel And Small Boat Hull Anti-Fouling Paint Leachate

Vessel And Small Boat In-Water Hull Cleaning Operations

Shore-Based NPDES Direct Discharge

Sources common to both Navy and Non-navy origin

Stormwater Runoff

Groundwater Transport

Atmospheric Deposition

Many general assumptions were used to derive the estimates of copper mass loads presented in this study and are applicable for all harbors under review. For Department of Defense vessels, many of the discharge-specific copper concentrations, ship system flow rates, in-port residence times, and data assumptions were based on NAVSEA 00T Nature of Discharge Reports (NOD) supporting the Uniform National Discharge Standards (UNDS) program. These NODs have recently been collectively published by the United States Environmental Protection Agency (1998c). Estimates of naval vessel copper contributions were derived from Navy-wide NAVSEA discharge information and applied to harbor-specific homeport information for Navy surface ships, service craft, and submarines.

For each major NAVSEA-identified copper containing discharge, a vessel-by-vessel copper load was quantified and summed across a region to determine the total contribution within each harbor. This sometimes necessitated re-interpretation or re-calculation of NAVSEA discharge information that was often presented as total fleet-wide impact instead of harbor specific influence. The Naval Sea Systems Command Shipbuilding Support Office (1998) provides on-line homeporting lists for active

and retired U.S. Navy vessels. Homeport information used for copper loading calculations by SSC San Diego was current as of September 1998.

There was less direct information available concerning civilian commercial vessel and pleasure craft copper contributions. To allow quantification of loading estimates from non-DoD vessels, information from NAVSEA NODs was applied to civilian craft in some situations. Studies of civilian pleasure boat hull cleaning operations in San Diego Bay were reviewed by SSC San Diego scientists[††] (PRC Environmental Management Inc., 1997) and similar loading calculations were performed for other harbors.

HULL ANTI-FOULING PAINT LEACH RATES

A major source of dissolved copper to most industrialized harbors is leachate originating from anti-fouling paint applied to hull bottoms. Designed to leach copper as a preventive biocide, these paints can result in significant copper inputs in small bays, marinas, or other confined water bodies where vessels are typically berthed.

The formula for hull leachate from any given ship can be expressed as:

$$CuLD_I = [\ (\ H_A \times Cu_L \,/\, 1{,}000{,}000{,}000\ \mu g/kg)\ ] \times I_P \qquad (1)$$

where

$CuLD_I$ = *Individual Vessel Copper Load (kg/yr)*

H_A = *Vessel wetted hull area in square centimeters* (cm^2)

Cu_L = *Copper Leach Rate per unit area* ($\mu g/cm^2/day$)

I_P = *Number of in-port days (days/year)*

NOTE: 1,000,000,000 represents unit conversion from µg to kg

Naval Vessel Wet Hull Area (H_A)

The NAVSEA NOD Hull Coat Leachate (Naval Sea Systems Command, 1997a) and table 633-5 *of Naval Ship Technical Manual* (Naval Sea Systems Command, 1996) contain pre-calculated tables of common naval ship wetted hull areas. For those few cases where there was no particular wetted hull listing in the above sources, the following Naval Sea Systems Command (1996) formula for calculating wetted hull area was used:

$$S = 1.7\,(L)\,(d) + (V/d) \qquad (2)$$

[††] McPherson, T. N. and G. B. Peters. 1995. The effects of Copper-based antifouling paints on water quality in recreational bat marina in San Diego and Mission Bay. Prepared for California Regional Water Quality Control Board, San Diego Region. Unpublished manuscript.

where

$S = \textit{Wetted hull area in } ft^2$

$L = \textit{Length of vessel between perpendiculars (ft)}$

$d = \textit{Molded mean draft at full displacement (ft)}$

$V = \textit{Molded volume of displacement (for seawater, 35 } ft^3 \textit{ per ton of displacement)}$

Vessel length and draft information was obtained from the on-line Internet *Naval Vessel Register* maintained by the NAVSEA Shipbuilding Support Office (NAVSHIPSO, 1998).

Pleasure Craft Wet Hull Area (H_A)

To estimate wetted hull area for pleasure craft, the following formula was used:

$$y = 0.2021x^2 - 0.2197x + 3.5571 \tag{3}$$

where

$y = \textit{Wetted hull area } (ft^2)$

$x = \textit{Boat length (ft)}$

This formula was derived by Grovhoug et al. (1989) based on unpublished data of sailing vessel length and wet hull area obtained from small boat manufacturers. Since approximately two-thirds of the pleasure craft surveyed in each harbor are sailing vessels, it was decided to apply the formula to all small boats. While hull area formulas would be different for power boats because of differences in hull dimensions, it was decided to use the above expression as a known means of determining hull area instead of attempting to estimate power boat hull areas without supporting data.

Paint Leach Rate

An average leach rate for Navy-formula anti-fouling paint of 17 $\mu g/cm^2/day$ was based on previous U.S. Navy studies of hull paint leachate (Naval Sea Systems Command, 1997a). There is no current published data on copper leach rates from commercial anti-fouling hull paints. The 17-$\mu g/cm^2/day$ leach rate was used in this report for both active Navy and pleasure craft hull-leaching calculations.

Because decommissioned vessels at the NISMF sites (Norfolk, Pearl Harbor) do not receive periodic repainting of anti-fouling paint, the typical hull leach rate in our calculations was changed from 17 $\mu g/cm^2/day$ to 1.0 $\mu g/cm^2/day$ to account for aging effects. Given the relatively long out-of-service period for many of these vessels, the 1.0 leach rate is conservative and actual leaching may be lower still. Past laboratory experiments with standard Navy ablative anti-fouling paints showed a lower release rate of 4.1 $\mu g/cm^2/day$ after 5.5 years with a further exponential reduction to around 2.5 $\mu g/cm^2/day$ after 7 years and 2.0 $\mu g/cm^2/day$ after 10 years. Additionally, as the hull paints age and the biocide efficiency becomes reduced, marine fouling organisms will begin to attach over time and could cover much of the hull surface area. This would result in further reductions of copper leachate from these vessels.

Leach rates have declined significantly with paint age (figure A-1). Valkirs et al. (1994) determined *in-situ* leach rates of between 1.1 and 6.0 $\mu g/cm^2$/day for five navy vessels with older hull paint applications in 1991. Hull paint conditions on these vessel classes, however, may not be indicative of paint leach rates currently encountered on newer naval vessels with newly applied paints. Conversations with civilian owners and marina dockmasters revealed that pleasure craft owners typically repaint more frequently than Navy vessels, somewhat justifying the use of the 17 $\mu g/cm^2$/day leaching value for civilian boats as well.

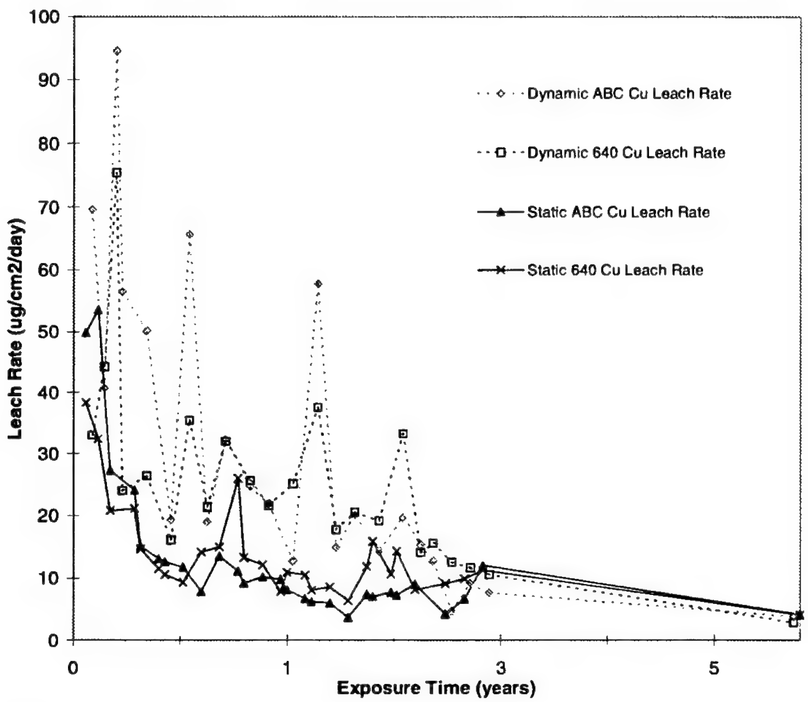


Figure A-1. Copper leach rate over time for test panels painted with Ameron (formerly Devoe) copper ablative anti-fouling paint (Devoe ABC #3) and International Courtaulds Coatings ablative anti-fouling paint (BRA 640).

Residence Time

Table 1 in Naval Sea Systems Command (1997a) contains in-port estimates for naval vessels. An overly conservative assumption for pleasure craft was adopted where all small boats were assumed to reside within a given harbor 365 days per year, since there was no reliable means to quantify days out-of-port.

IN-WATER HULL CLEANING

In-water hull cleaning is a fundamental maintenance operation common to naval vessels and pleasure craft designed to reduce the amount of bottom growth from marine fouling organisms. Large civilian commercial vessels such as tankers and container ships typically do not have their hulls cleaned in U.S. ports, but rather take advantage of lower foreign labor costs to have hulls cleaned at non-U.S. sites.

In-water hull cleaning releases copper as part of the hull scrubbing process. However, a fundamental difference exists in determining hull cleaning copper load when comparing civilian hull cleaning estimates and NAVSEA estimates for naval vessels. Critical terms for determining the hull-cleaning load include (a) release rate per unit area cleaned or, alternatively, the concentration of a cleaning plume, and (b) frequency of cleaning. The Navy formula bases the hull cleaning load estimate on a unit area of cleaned hull that releases a set amount of dissolved copper when cleaned by a mechanical apparatus. The civilian hull-cleaning estimate was based on a volumetric plume approach, and depends on the plume dissolved copper concentration generated by hand-held scrubbing operations, as well as the plume volume.

The formula used for calculating the hull cleaning copper load for an individual cleaning event for naval vessels is expressed as

$$CuLD_I = [\ (\ H_A\ x\ Cu_R\ )\ /\ 1{,}000\ g/kg\ ]\ x\ C_E \qquad (4)$$

where

$CuLD_I$ = *Individual Vessel Copper Load (kg/yr)*

H_A = *Vessel wetted hull area in square meters (m^2)*

Cu_R = *Copper Release Rate per unit area cleaned (g/m^2)*

C_E = *Number of cleaning events per year (clean/yr)*

NOTE: 1,000 represents unit conversion from g to kg

Release Rate (Cu_R)

Navy. The NAVSEA hull cleaning copper release rate estimate is based on the quantity of copper released per square meter of surface area cleaned (Naval Sea Systems Command, 1997b). For the purposes of these calculations, the NAVSEA generated SCAMP cleaning formula was used with a dissolved copper concentration from experimental Navy studies in San Diego Bay of 0.000107 g/L verses the total copper value of 0.00195 g/L reported by Naval Sea Systems Command (1997b). This dissolved-to-total copper ratio was approximately 5.5%. Based on the dissolved copper concentration and SCAMP formula below, a copper release value of 0.3 g/m^2 dissolved Cu per cleaning was determined and used in the above loading equation (*Formula 4*).

NAVSEA SCAMP Formula:

$$Cu/A = C\ (g/L)\ *(F/R) \qquad (5)$$

where

Cu/A = *Copper mass per unit area in g/m²*

C = *Dissolved copper concentration in g/L (given by NAVSEA as 0.000107 g/L)*

F = *SCAMP Flow Rate in L/hr (given by NAVSEA as 51,100 L/min)*

R = *Rate of travel per unit time in m²/min (given by NAVSEA as 20.8 m²/min)*

Pleasure Craft. Data from two studies on pleasure craft cleaning in San Diego Bay were applied to pleasure craft from all harbors, and use average plume concentrations along with an associated cleaning plume volume. McPherson and Peters[††] measured an average plume concentration of 30.2 µg/L (dissolved Cu) for a small boat cleaning event in San Diego. PRC Environmental Management, Inc. (1997) then applied a volumetric approach to estimate the plume size and allow conversion to mass loading. The hull cleaning loading formula for civilian hull cleaning is expressed as:

$$CuLD_I = [((Cu_C \times P_L) / 1{,}000{,}000{,}000\ \mu g/kg) \times 1{,}000\ L/m^3\ ] \times C_E \qquad (6)$$

where

$CuLD_I$ = *Individual Pleasure Craft Copper Load (kg/yr)*

Cu_C = *Average hull cleaning plume concentration (µg/L)*

P_L =*Plume generated by cleaning event* (m³/*clean) as defined by PRC (1997) to be:*
(6m +boat length + 6 m) x (6m +boast width + 6m) x (6m boat basin depth) with average boat length assumed to be 25 ft (7.6 m) and boat width 8.2 ft (2.5 m) and mooring basin depth of 19.7 ft (6 m)

C_E = *Number of cleaning events per year (clean/yr)*

NOTE: 1,000,000,000 represents unit conversion from µg to kg (1 kg = 1,000,000,000 µg)
1,000 represents unit conversion from m³ to Liters (1 m³ =1,000 L)

Cleaning Frequency (C_E)

Naval ship hull cleaning is initiated if underwater inspection reveals a pre-set level of marine fouling. Actual hull cleaning evolutions were identified for 1997 for each homeport and ship-specific loading based on NAVSEA (00C)-reported cleaning during that year (i.e., wetted hull area times Cu release rate, and converted from grams to kilogram).

In-water hull cleaning for pleasure craft is estimated to occur about once a month for those owners who regularly maintain their boats. Based on conversations with marina operators in San Diego and

[††] McPherson, T. N. and G. B. Peters. 1995. The effects of copper-based antifouling paints on water quality in recreation bat marina in San Diego and Mission Bay. Prepared for California Regional Water Quality Control Board, San Diego Region. Unpublished manuscript.

Pearl Harbor, there is a small proportion of owners who do not follow this cleaning frequency. To quantify this difference in the formula, a cleaning frequency of 10 cleanings per year per vessel verses 12 per year was used to adjust for those boats not cleaned each month.

SEAWATER COOLING

High-speed pumps aboard most Navy vessels are designed to pump in ambient water to provide cooling to various mechanical and electrical shipboard systems prior to discharge back to the surrounding waters. Seawater cooling has potential as a significant source of copper loading based primarily on high system flow rates and elevated discharge concentrations (Naval Sea Systems Command, 1997c). Loading estimates are dependent on an average discharge concentration and individual ship flow rate and are calculated by

$$CuLD_I = [\ (SC_C \times SC_F) \times 3.7854\ ] \ /\ 1{,}000{,}000{,}000\ \mu g/kg \qquad (7)$$

where

$CuLD_I$ = *Individual Vessel Copper Load (kg/yr)*

SC_C = *Seawater Cooling Average Discharge Concentration (µg/L)*

SC_F = *Seawater Cooling Annual Ship-specific Flow (gal/yr)*

NOTE: 3.7854 represent unit conversion where 1 gal = 3.7854 liters
1,000,000,000 represents unit conversion from µg to kg

Discharge Concentration (SC_C)

The average seawater discharge concentration used in this report was calculated directly from a NAVSEA (00T) UNDS discharge sampling database, and is somewhat different than the NAVSEA Seawater Cooling NOD. One Sampling Episode Report for the USNS *Laremie* was not provided; however, the remaining seawater cooling data are summarized below.

The dissolved copper contributed by each ship's measured discharge was computed (effluent minus influent). One Nimitz-class aircraft carrier, one Wasp-class Amphibious Assault ship, one Harpers Ferry-class Amphibious Transport, and one Arleigh Burke-class destroyer were sampled by NAVSEA. The geometric mean concentration was calculated as 14.4 µg/L, which was used as SC_C in the loading calculations. The receiving water concentration adjacent to the vessel undergoing sampling was not addressed by the NAVSEA Seawater Cooling NOD. Review of the NAVSEA Sampling Event reports revealed that influent data were collected after water had been drawn into the ship and sampled from within the hull, typically, at a pump casing or vent drain. Copper contributed by the hull-to-pump piping is not known. Almost all of the NAVSEA influent dissolved copper numbers (5 to 17.9 µg/L) are already higher than the Federal Water Quality Criteria (WQC) of 2.9 µg/L, or the proposed California Toxic Rule limit of 3.1 µg/L dissolved copper♦.

♦ Federal Register, volume 62, page 42159, August 5, 1997.

Flow Rate

Naval Sea Systems Command (1997c) reported annual flow rate by vessel class and typical residence time in port for that class. To determine annual flow rate by individual vessel, the annual rate was divided by the number of vessels in that class (as listed by NAVSEA). Additionally, different pump speeds are employed depending on vessel status. Since most in-port vessels have less system equipment on-line, pump rates are lower. Pump rates are higher during start-ups and transit because of increased system cooling demands. Because of these different pump speeds, three seawater cooling loading estimates were generated for each ship based on in-port time, system start-up while in-port, and transit from harbor out to 12 nmi. For estimates of seawater cooling loading during transit, SSC San Diego changed the time of transit from 4 hours to reach the 12 nmi limit (originally used by NAVSEA) to 1 hour to represent clearing the general harbor area.

FIREMAIN DISCHARGE

Shipboard firemain systems are designed to provide continuous pressurized water for emergency firefighting. Firemain discharge is another high-volume continuous vessel discharge, and requires the same information on average dissolved copper concentrations and flow rate. As such, the formula used is similar to the seawater cooling discharge formula, with the exception that a daily flow is determined and applied to the annual in-port days for that vessel class:

$$CuLD_I = [\ (FM_C \times FM_F \times 3.7854\ )\ /\ 1{,}000{,}000{,}000\ \mu g/kg\ ] \times I \qquad (8)$$

where

$CuLD_I$ = *Individual Vessel Copper Load (kg/yr)*

FM_C = *Firemain Discharge Geometric Mean Discharge Concentration (µg/L)*

FM_F = *Firemain Ship-specific Daily Flow (gal/day) converted from original gallons per minute (GPM) by flow/min x 60 min/hr x 24 hr/day*

I = *Number of in-port days (days/year)*

NOTE: 3.7854 represent unit conversion where 1 gal = 3.7854 Liters
1,000,000,000 represents unit conversion from µg to kg

Discharge Concentration

To simplify the average concentration determination, the geometric mean of the NAVSEA measured firemain effluents minus the geometric mean of the firemain influents was used to derive a value of 16.5 µg/L dissolved copper.

Flow Rate

Based on the NAVSEA NOD for Firemain Discharge (Naval Sea Systems Command, 1997d), the individual vessel daily flow was calculated using the NAVSEA GPM firemain pump speed by vessel class.

OTHER NAVAL VESSEL DISCHARGES

Non-Oily Waste Discharge

The geometric mean dissolved copper concentration for non-oily waste discharge was as high as 149 µg/L (Naval Sea Systems Command, 1997e) during sampling conducted aboard an aircraft carrier. Unfortunately, there is no quantifiable flow information from the NAVSEA NOD presented for other surface ship classes to perform the required loading calculations. As this information becomes available, the contributions from this discharge category can be re-evaluated.

Graywater Discharge

Graywater discharge was initially calculated for Norfolk homeported vessels. Graywater discharge was determined to be a relatively minor copper load source, so further load calculations for Pearl Harbor and San Diego were not included.

STORMWATER RUNOFF

Non-point source runoff is recognized as a significant contributor of pollutants to any watershed (United States Environmental Protection Agency, 1998a). Stormwater runoff is also the most subjective copper source in these loading determinations because of variations in using site-specific Event Mean Concentrations (EMC). Stormwater contaminant input can be estimated across a watershed or sub-watershed area based on the association of contaminant loading as a function of land use within the watershed (Schueler, 1987). A key concept is that the amount of surface runoff, potentially carrying contaminants, increases as a function of the storm event and, more importantly, the amount of overall urbanization at the site. Urbanization directly influences the degree of runoff through greater site imperviousness caused by the addition of structures, streets, and parking lots common to this land use category. Schlueler (1987) demonstrated that as the percentage of imperviousness rises, less stormwater is able to naturally percolate into the surrounding soil and is directed as runoff from a given site.

Flow-weighted average pollutant concentrations in stormwater runoff have been measured and reported by the United States Environmental Protection Agency from nationwide monitoring in the late 1970s and 1980s as part of the Nationwide Urban Runoff Program (NURP) (United States Environmental Protection Agency, 1983). Calculation of an Event Mean Concentration (EMC) from flow-weighted data is critical in determining stormwater contaminant loading. Land use EMCs for total copper were reported by the USEPA as 33.0 µg/L (Residential), 27.0 µg/L (Mixed Commercial), and 29.0 µg/L (Open/Nonurban). Local monitoring studies and generation of region specific EMCs are discussed in the relevant harbor sections.

The EMC for roadways may be more variable. Copper, contained in some brake linings, engine parts, and tires, is thought to be a significant contribution to runoff from roadways. For instance, Sansalone and Buchberger (1997) reported a geometric mean dissolved copper concentration of 103 µg/L over four storm events from a Midwestern freeway system. The Federal Highway Administration determined a copper road runoff EMC of 42.8 µg/L, which was used for the Road EMC in this study (Federal Highway Administration, 1990).

Simple Method for Stormwater Modeling

Schueler (1987) presents a modeling method to predict stormwater pollutant loading called the "Simple Method," which relates the amount of precipitation and associated runoff by land use category. This formula was used to generate copper loading estimates by sub-watershed within each harbor's drainage basin.

Stormwater load for each land use category in each sub-watershed is calculated by:

$$L = [\, P \times P_J \times R_V / 12 \,]\, C \times A \times 2.72 \tag{9}$$

where

- L = Storm Pollutant Load (pounds/yr)
- P = *Rainfall in inches over desired time interval (assume annual rainfall) (in/yr)*
- P_J = *Factor that corrects "P" for storms that produce no runoff (assumed to be a constant at 0.9 by Schueler)*
- R_V = *Runoff coeffiencient which expresses the fraction of rainfall which is converted into runoff and expressed as $R_V = 0.05 + 0.009\ (I)$ with "I" being the percent of imperviousness at a site by land use*
- C = *Flow-weighted mean concentration of the pollutant of concern (mg/L) (i.e., EMC by land use)*
- A = *Area of the site of concern (acres)*

NOTE: 12 and 2.72 are unit conversion factors

The Simple Method was originally designed for calculating loading from sites that were less than one acre in size. As such, it does not attempt to quantify any baseflow components that could supplement annual runoff volume, especially in low-density residential watersheds. Schlueler adds a "Baseflow" term to equation 9 to give:

$$L = [\, (P \times R_{VA}) - (P \times P_J \times R_V / 12) \,]\, C_B \times A \times 2.72 \tag{10}$$

where

- R_{VA} = *Annual Runoff Coefficient*
- C_B = *Average dry-weather pollutant concentration (mg/L)*

All others terms the same.

R_{VA} is manually derived from a graph showing the difference between Storm R_V and Annual Runoff R_V, presented as table A.2 in Schueler (1987) and in figure A-2, which lists runoff coefficients as a function of site imperviousness. In addition, since many dry weather pollutant concentrations are often at ambient background levels, Baseflow EMCs (C_B) are typically adjusted downward from

monitoring EMCs to account for this effect. Harbor specific R_{VA} and C_B values based on regional determination of imperviousness, and modifications to EMC by land use category were determined for each site. A watershed-level stormwater contribution, therefore, consists of a stormwater runoff component and a baseflow component for purposes of this report.

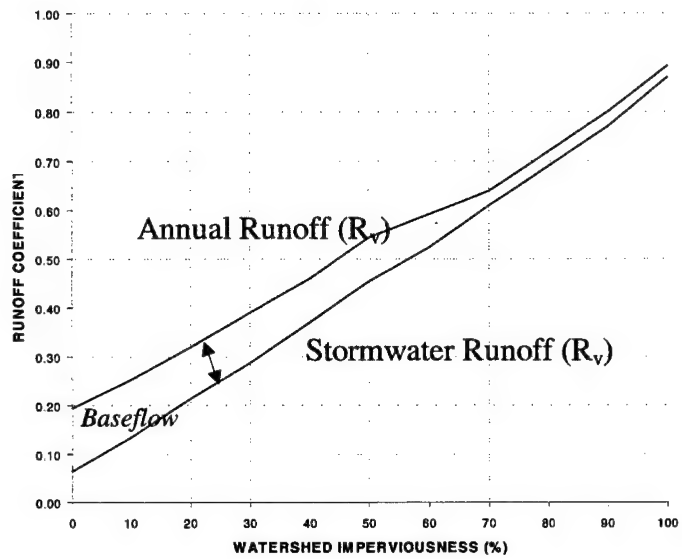


Figure A-2. Relationship between annual runoff and stormwater runoff as a function of watershed imperviousness (Schueler, 1987).

OTHER SOURCES

Atmospheric Deposition

Atmospheric deposition is another watershed level contributor for various contaminants including copper (United States Environmental Protection Agency, 1997). Site specific assumptions are presented in the individual harbor discussion sections. For all cases, the calculation of atmospheric copper loading assumed deposition to the marine waters of a harbor. Contributions to the surrounding land areas are assumed to be incorporated into the stormwater runoff for that region.

Groundwater Transport

There is no current loading term for subterranean groundwater transport of pollutants because of a lack of understanding of the volume of groundwater generated by a given watershed, potential transport of contaminants of concern within groundwater flow, or fate and effects of metals in this medium. Given that groundwater transport may represent a strong component of freshwater input to an estuarine environment, its role could be significant if copper contamination is present while in contact with groundwater. Pearl Harbor, with its many natural springs and shallow aquifer, is an example of a region that could be impacted through groundwater transport (Grovhoug, 1992). However, lacking information on volume and potential copper concentration from each of the harbors under review, copper loading from groundwater transport cannot presently be determined.

Sediment Flux

There is no current loading term for copper flux into or out of marine sediments. Sediments may act as a sink for copper in many urbanized harbors, and have been shown to release previously bound copper back into the water column depending on sediment conditions (Chadwick et al., 1993). However, there is little data regarding overall harbor-wide copper budgets. Chadwick et al. (1993) found that while some sediment sites serve as copper sinks, others act as copper sources. This observed effect was a site-specific feature and would require detailed harbor sediment sampling to accurately estimate harbor-wide contributions.

Visiting Naval Vessels

United States and foreign naval vessels frequently berth for short periods of time in U.S. ports (notably Pearl Harbor) following major exercises, before and after oversea deployments, and as part of official port visits. These in-port times vary depending on operational and scheduling requirements. An added complexity in quantifying vessel discharge from temporary visitors is the periodicity of local exercises that may occur annually or biannually.

OTHER DATA ASSUMPTIONS

The USEPA promulgates a total-to-dissolved copper conversion factor of 0.83 (total conc. x 0.83 = dissolved conc.) (United States Environmental Protection Agency, 1995) that is more conservative than the site-specific conversion factor determined for Norfolk by Atlantic Division, Naval Facilities Engineering Command [*] and CH2M Hill, Inc.[†]. A conversion factor is simply a means of calculating a dissolved metal value given a measured total metal concentration.

The geometric mean value of the Norfolk copper conversion factor was calculated (from the original LANTDIV reported values) to be 1.45 (total conc./1.45 = dissolved concentration). Although such calculations may be more accurate based on locally determined chemical conversion factors, SSC San Diego used the USEPA value as an overly conservative estimate for converting any total-to-dissolved copper loads.

---

[*] Atlantic Division, Naval Facilities Engineering Command. 1993. Ambient copper water concentrations for eight stations. Norfolk, VA.

[†] CH2M Hill, Inc. An integrated approach to obtaining optimal discharge permits. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, VA. Detroit, MI.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 1998

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
COPPER LOADING TO U.S. NAVY HARBORS
Norfolk, VA; Pearl Harbor, HI; and San Diego, CA

5. FUNDING NUMBERS
PE: OMN
AN: DN307504
WU: ME83

6. AUTHOR(S)
H. D. Johnson, J. G. Grovhoug, SSC San Diego;
A. O. Valkirs, Computer Sciences Corporation

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
SSC San Diego
53560 Hull Street
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER
TD 3052

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Sea Systems Command (005C)
2531 Jefferson Davis Hwy
Arlington, VA 22242–5160

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENTS
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This document identifies several sources of copper loading into four Navy harbors within the continental United States and Hawaii. The degree of copper loading as dissolved copper is quantified by source within each harbor. Although copper sources and their respective percent of the total load vary between harbors, some similarities are apparent. Hull anti-fouling bottom paint leachate is the principal dissolved copper source in all harbors followed by certain vessel flow-through discharges. Other sources were calculated to be smaller loading factors, sometimes contributing less than 1% of the total dissolved copper load. The dissolved copper calculations in this report are based on numerous assumptions, which in turn were supported by data that also varied in terms of quality and availability. Consequently, some loading estimates are considered potentially more accurate than others.

14. SUBJECT TERMS
Mission Area: Environmental Assessment
copper
ecology
marine chemistry

15. NUMBER OF PAGES
86

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

21a. NAME OF RESPONSIBLE INDIVIDUAL	21b. TELEPHONE *(include Area Code)*	21c. OFFICE SYMBOL
H. D. Johnson	(619) 553-5331 e-mail:cjohnso@spawar.navy.mil	Code D3621

INITIAL DISTRIBUTION

D0012	Patent Counsel	(1)
D0271	Archive/Stock	(6)
D0274	Library	(2)
D027	M. E. Cathcart	(1)
D0271	D. Richter	(1)
D3601	P. Seligman	(5)
D361	M. Putnam	(1)
D361	S. Apitz	(1)
D361	R. George	(1)
D361	V. Kirtay	(1)
D362	J. Grovhoug	(1)
D362	B. Chadwick	(1)
D362	C. Katz	(1)
D362	G. Key	(1)
D362	K. Richter	(1)
D362	A. Valkirs	(1)
D362	P. Wang	(1)
D362	B. Wild	(1)
D362	A. Zirino	(1)
D3621	S. Harrell	(1)
D3621	R. Gauthier	(1)
D3621	C. Johnson	(49)
D3621	B. Johnston	(1)

Defense Technical Information Center
Fort Belvoir, VA 22060–6218 (4)

SPAWARSYSCEN Liaison Office
Arlington, VA 22202–4804

Center for Naval Analyses
Alexandria, VA 22302–0268

Navy Acquisition, Research and Development
Information Center (NARDIC)
Arlington, VA 22244–5114

GIDEP Operations Center
Corona, CA 91718–8000